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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled CANADIAN INTERFUEL SUBSTITUTION MODEL submitted by ROBERT ACTON in partial fulfilment of the requirements for the degree of Master of Science.

ABSTRACT

A mathematical model has been developed to simulate the interfuel substitution process in Canada. This process is represented by the consumer when he enters the energy marketplace to bargain for a fuel form to satisfy his energy needs.

The model was used to analyze the past behavior patterns of energy consumers and to project some possible future scenarios of energy consumption under differing hypotheses.

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CHAPTER I

INTRODUCTION

The Department of Energy, Mines and Resources of the Canadian government has already clearly stated (4) the need for a comprehensive understanding of the dynamics of energy supply and demand in Canada. They correctly point out that this understanding must include knowledge regarding the interactions that the energy sector has within a wide range of complex Canadian social and economic structures. From this perspective the Department of Energy, Mines and Resources has proposed a qualitative framework of important factors to be considered when formulating energy policy (4)[1].

The necessity of clearly specifying a framework and the corresponding components for analysis is well recognized here. However, the following thesis is based on the conviction that an equally essential and useful ingredient in the analysis methodology is the utilization of 'large-scale'[2] mathematical models, particularily in instances such as energy policy formulation where many of the important components are easily quantified. The functions that 'large-scale' mathematical models perform include:

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[1] see figure I.1
[2] large-scale models are defined here as multiple, open system models.

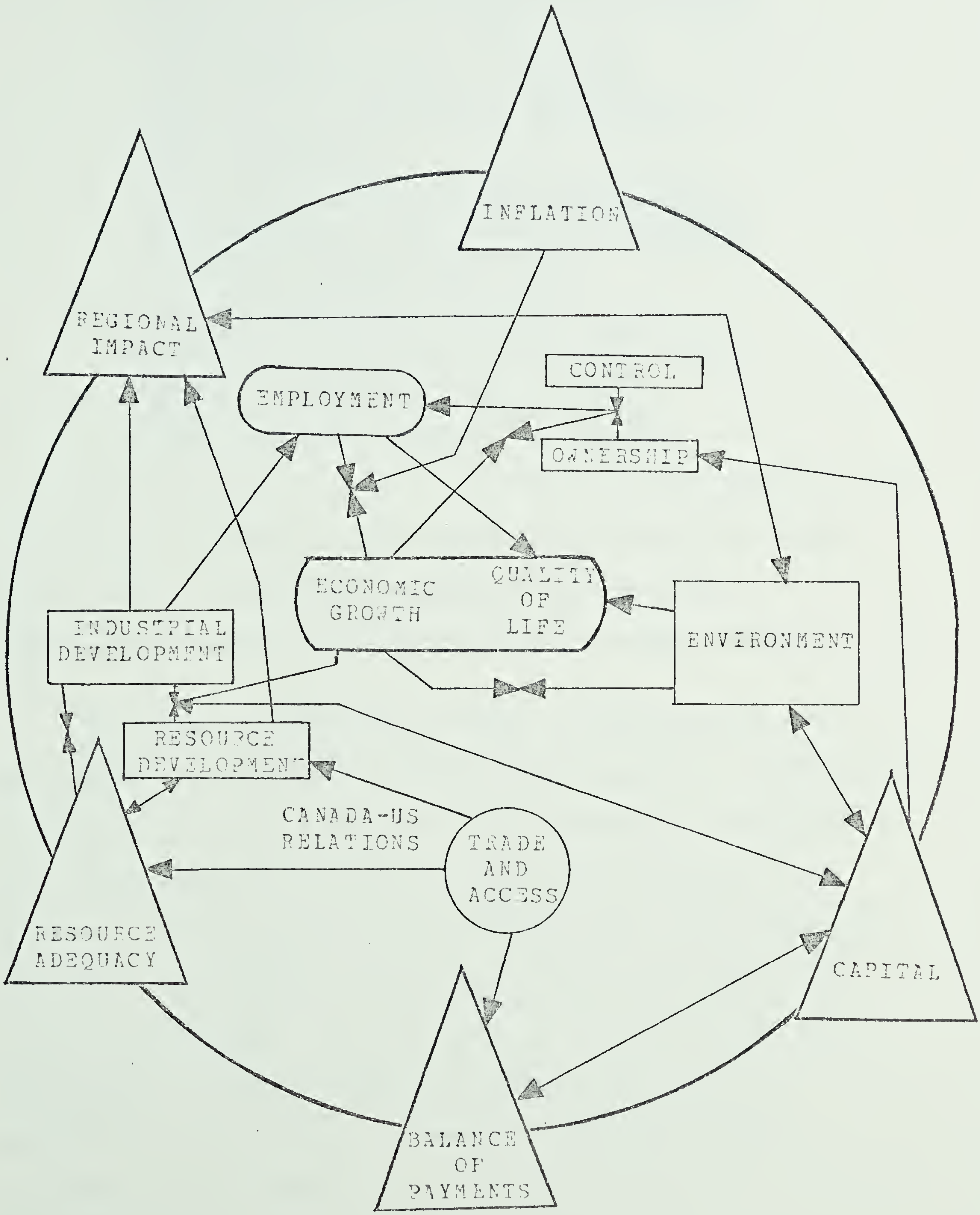

FIGURE I.1 - QUALITATIVE FRAMEWORK WITHIN WHICH THE DEPARTMENT OF ENERGY, MINES AND RESOURCES PROPOSES TO FORMULATE CANADIAN ENERGY POLICY.

- Since it is a relatively simple task to divide large-scale mathematical models into sub-components, these models facilitate easier component by component analysis within the framework of a broad perspective.
- The quantification of variables required by mathematical models produces more concise definitions of abstract mental concepts.
- The quantitative results produced by large-scale mathematical models yield an understanding of the relative importance of interrelated factors and the impacts that input changes may cause.
- In the particular case of energy policy analysis, it is vital that the available information concerning future expected quantities such as energy supplies, demand and prices be as quantitatively accurate as possible.

Therefore, the primary objectives of this thesis are to expand the information base required to formulate energy policy and to illustrate the use of 'large-scale' mathematical models as valuable tools in this process.

With these objectives in mind, a mathematical model describing the interfuel substitution process in Canada was developed. Only the behavior of the consumer is depicted in this model wherein interfuel substitution refers to the process in which consumers are engaged when they enter the marketplace to bargain for energy forms to satisfy their energy requirements. This process is a major factor in determining energy consumption patterns and must be understood before policy decisions affecting energy consumers can be made.

CHAPTER II

LITERATURE REVIEW

Not until recently have economists and government policy analysts become concerned with problems related to interfuel substitution. This statement is fully supported by the fact that an insignificant quantity of literature on this topic was published before 1970.

Energy problems in the first half of this century were greatly simplified by the facts that there was generally an abundant supply of cheap energy and the environmental impacts of energy projects were relatively small. Technological changes since 1900 have contributed to a continual expansion and diversification of the Canadian energy base. In addition to coal being a valuable energy source, these technological changes have resulted in crude oil, natural gas, and electricity also being important energy forms available to the ultimate users of energy in Canada. Even the producers of electricity have a wider choice of primary energy forms available to them as a result of these technological changes. The electricity producers of today may choose from hydro, natural gas, crude oil, coal or nuclear power as primary sources of energy for electricity generation.

It was the introduction of these alternative fuel forms that gave rise to the first real occurences of interfuel

competition in Canada. However, the situation that existed until very recently may be described as a "consumer's market" where energy producers were competing with each other for a share of the market. This mentality still existed in 1968 (9).

In the late 1960's the emergence of environmental concerns added a new dimension to the already complex nature of the interfuel competition process. Canadians began to acquire a consciousness of the impacts that resource development (including energy resources) and subsequent consumption have on our natural environment. There can be no question that environmental concerns have affected the development and consumption patterns of energy resources.

New circumstances since 1972 have fundamentally altered the situation regarding energy resources in Canada. It is now recognized that Canada is entering a period characterized by the scarcity of low-cost energy. There is an increasing pressure to re-examine our future energy requirements and to define more clearly the criterion that should be employed in satisfying our energy demands. Included in the decision criterion there must be the consideration of the technological restrictions, comparative efficiencies (19,33) and costs, and the environmental impacts of fuel utilization. Manifestations of these new concerns and issues are available in the form of recent conferences and government studies (3,14,15,16,23).

Despite the fact that in the last decade there have been an increasing proliferation of studies and reports addressing the issues of energy demand and interfuel substitution, the theoretical foundations of these endeavors must still be considered in their infant stages. Gonzalez (9) and Rose (22) have analyzed and discussed the determinants and the consequences of interfuel competition from the perspective of classical demand theory as outlined by Samuelson and Scott (24). That is, through the identification of the price of fuels and their substitutes, consumer tastes and consumer incomes, it is possible to qualitatively trace the impacts that price, taste or income changes will have on the consumption of particular fuels, their substitutes, and their complements.

Important contributions towards understanding the utilization of energy resources have been made by studies applying an economic analysis to the environmental problems (6,14). However, these developments have been of a more general nature relating to the classification of a broad spectrum of 'resources' and the specification of their individual characteristics.

In addition, substantial theoretical advances have been made through the use of mathematical simulation techniques. Searl (25) has described several energy models which have been developed in the United States. Foell (8) and Palmedo (18) have demonstrated how the use of the mathematical models can guide the process of energy research and assist

in policy formulation. Although the Behrens (2) model of natural resource utilization does not discuss energy usage per se, his model structure does identify, in a very aggregated way, the critical factors to be examined in the analysis of any natural, nonrenewable resource. On the other hand, Baughman (1) and Khazzoom (11,12) have both conducted studies on very specific, well-defined aspects of energy problems. Martin Baughman has constructed a model of the interrelationship of energy supply, demand and price in the United States. His work in the area of interfuel substitution by consumers is one of the first quantitative approaches to this subject. Khazzoom is currently in the process of constructing several independent single-equation models of energy demand in Canada. These models describe sector-by-sector demand for individual energy sources. It is expected that Khazzoom will interrelate these models once he has constructed equations for all the sectors and all the energy forms.

A very different approach to energy demand problems has been presented by Collins, Warren and Wozniak (5). They consider the possibility of inter-sector cooperation, rather than competition, in the utilization of fuels. As a result, they have developed a scheme for the optimal allocation of crude oil, natural gas, and coal among the power, plastics and steel industries.

Since the field of energy research within its present context is so new a literature review is never complete.

Several times each year new ideas, approaches and results are emerging.

This thesis was completed with the understanding that the above mentioned works constituted the major contributions to energy demand research thus far.

CHAPTER III

GENERAL DESCRIPTION AND DEVELOPMENT OF THE MODEL

Three basic stages are involved in developing a 'large-scale' mathematical model. In the first stage the theoretical foundations of the model are outlined in a qualitative manner. It is in this stage of model development that the model assumptions, levels of aggregation, and the major variables and their interrelationships are identified. The second stage of the model development consists of quantifying the variable interrelationships in a suitable mathematical form. Finally, in the third stage, the validity of the mathematical model is tested and the model as it exists is either accepted, accepted subject to improvements, or rejected. Although the stages of model development have been described as occurring in a single sequential process, these stages are generally followed in a repetitive fashion as the model builder converges on a valid model; i.e. theory, mathematical representation, validity, theory, mathematical representation, etc..

The development of the Canadian Interfuel Substitution Model will be described with reference to the three stages of model development.

A. THEORY

The basic concepts required to understand the economics of energy demand and interfuel substitution have already been outlined and expanded upon by Khazzoom (11) and Baughman (1). The development of these theories, as extensions of the classical demand theory, originated around 1963 (4). In order to save the reader time, a summarized account of the theory will be presented here.

The total demand for energy resources exists in two fundamental forms - captive demand and free demand.

Captive demand is that part of the total demand which is immobilized by past commitments. These past commitments may include investment in single-fuel transportation systems (i.e. natural gas pipeline) or single-fuel conversion equipment (i.e. electric stove). Because of these commitments, the consumer is not in a position of considering interfuel substitution.

On the other hand, free demand is that portion of the total demand which is free from any commitments and may be satisfied by any number of energy fuel forms depending on the economic and technological conditions prevailing at the time. The free demand of any given sector is equal to the sum of the replacement demand and incremental demand for that particular sector. Replacement demand originates from consumers who were, in the past, committed to a particular fuel. However, these consumers are no longer tied to any one

fuel and they are now entering the energy marketplace in search of possible substitute fuels. The consumers who possess replacement demand behave as if they were in the energy marketplace for the first time. That is, they consider all fuels as possible substitutes including the particular fuel that they utilized prior to entering the marketplace. Incremental demand is that portion of total demand made up of new consumer needs or incremental growth in total demand. Because of the sensitivity of free demand to market conditions, it is often referred to as the 'market sensitive' demand.

The ratio of free demand to captive demand for energy resources in Canada has generally been very small in the past. This situation is partly explained by the fact that the costs of conversion equipment have been relatively high compared to the fuel costs. As a result, consumers have been committed by large investments to their particular conversion equipment and they are unable or unwilling to make spontaneous, short-range decisions concerning fuel choices. However, it is possible that the ratio of free demand to captive demand will increase in the future if fuel prices escalate at a faster rate than conversion equipment costs.

The criteria that energy consumers with free demand employ in committing their demand to a particular fuel form are identical to those identified in classical demand theory. These criteria consist of a relative comparison of

fuel prices and the prices of their complements (i.e. fuel-consuming appliances) and a consideration of the non-economic requirements (i.e. tastes) of the consumer. A contemporary example of the effects that changing tastes may have on the interfuel substitution process is the rise of environmental concerns producing demands for cleaner energy forms. In addition, it must be remembered that consumers may diminish their free demand, and hence their total demand, for energy fuels by substituting labour or capital for their requirements. Examples of this would be the substitution of higher quality insulation for space heating or the substitution of a bicycle for an automobile.

This concludes the summary of the basic theoretical concepts required to analyze the demand for energy and the interfuel substitution process. As the results and conclusions are discussed in later chapter, more detailed theoretical observations will be made.

B. THE MODEL

A mathematical model which simulates the interfuel substitution process for energy demand in Canada has been developed. The model, with its levels of aggregation, framework, and mathematical structure has been adopted in its basic form from the work done by Baughman (1). The only major structural changes that have been made to the Baughman model relate to the nature of the 'distribution multipliers'. The distribution multipliers are a set of mathematical relationships which simulate consumer behavior in the energy marketplace. These multipliers determine what proportions of the total free demand for energy will be satisfied by each of the fuel forms available. A more detailed description of the distribution multipliers will be given later[1].

Energy demand in the model is assumed to arise from four sources - residential and commercial space heating, industrial process heating, transportation, and electricity generation. In turn, these energy demands are assumed to be satisfied by some combination of the four "end-use" energy forms available - crude oil, coal, natural gas, and electricity. Crude oil, coal and natural gas are referred to as primary energy forms since they are converted directly from their natural occurring forms into useful energy. On the other hand, electricity is considered a secondary energy

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[1] refer to Appendix B

form because it is produced from primary energy sources such as crude oil, coal, natural gas, uranium and hydro.

For convenience, all energy demands and their corresponding supplies are treated in the model in their BTU (British Thermal Unit) equivalent forms. The conversion factors are presented in Appendix A.

Figure III.1 graphically depicts the model with its boundaries, levels of aggregation, and interrelationships of variables.

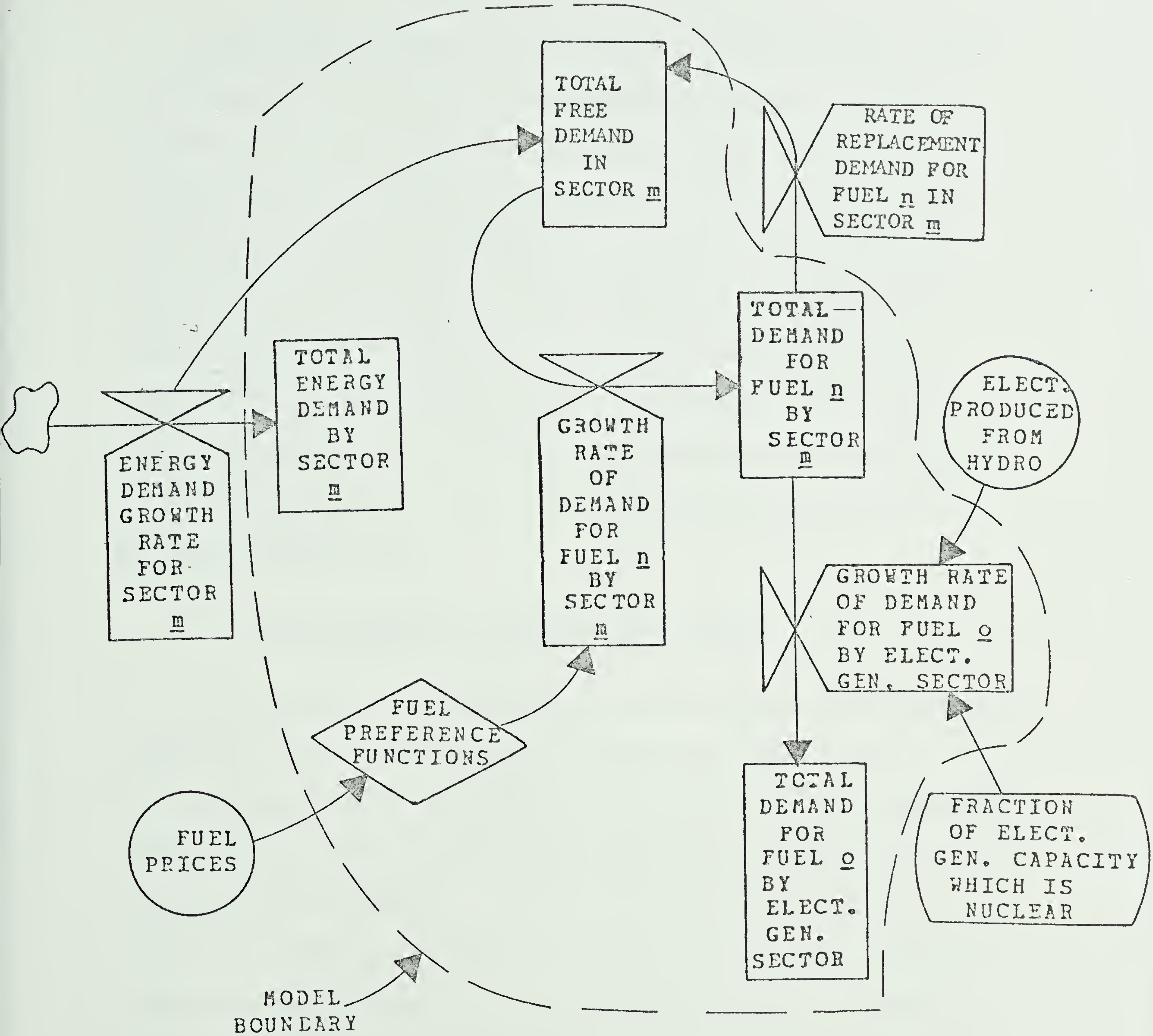
The demand sectors represented in the model, with the exception of the electricity generating sector, all have identical mathematical structures. The electricity generating sector will later be treated separately. Thus, the primary consuming sectors (transportation, residential and commercial, and industrial) each have within them three major sub-components:

1. determination of sector free demand

2. calculation of distribution multipliers

3. determination of current sector demand for each fuel.

In the process of simulating the sectors' interfuel substitution behavior the model calculates, in a sequential fashion, the values of the three sub-components for each time period and returns the new values in preparation for



Sector m = Residential-Commercial, Industrial, or Transportation.
Fuel n = Coal, Crude Oil, Natural Gas or Electricity.
Fuel o = Coal, Crude Oil, Natural Gas, or Nuclear.

FIGURE III.1 - STRUCTURE OF THE CANADIAN INTERFUEL SUBSTITUTION MODEL

the calculations at the next time period.

Since the mathematical notation for subscripts, which is employed in the following explanations, is slightly irregular it will now be briefly expounded upon. The variable subscripts are represented by $\underline{m}$ and $\underline{n}$ and they identify two basic characteristics of the variables with which they are associated. The subscript $\underline{m}$ identifies the demand sector (residential-commercial, transportation, industrial or electricity generating) which the variable refers to while the subscript $\underline{n}$ identifies the particular energy source (coal, oil, gas or electricity) which the variable refers to.

1. DETERMINATION OF SECTOR FREE DEMAND

As outlined in section III.A, the sector free demand is composed of two components - replacement demand and incremental demand. According to its respective components, sector free demand (market sensitive demand) may be described as follows:

$$MSD\underline{m}(t) = ID\underline{m}(t) + RD\underline{m}(t) \qquad \text{(III.1)}$$

$$ID\underline{m}(t) = RG\underline{m} \times TD\underline{m}(t) \qquad \text{(III.2)}$$

$$RD\underline{m}(t) = [\underline{m}CLRI\underline{n}(t) \times \underline{m}D\underline{n}(t)] \qquad \text{(III.3)}$$

where
- $\underline{m}$ = the demand sector in question
- $\underline{n}$ = the energy fuel in question
- $MSD\underline{m}$ = the market sensitive demand for sector $\underline{m}$ at time t.
- $ID\underline{m}$ = the incremental demand for sector $\underline{m}$
- $RD\underline{m}$ = the replacement demand for sector $\underline{m}$
- $RG\underline{m}$ = the rate of growth of energy demand for sector $\underline{m}$
- $TD\underline{m}$ = the total energy demand of sector $\underline{m}$
- $\underline{m}CIRT\underline{n}$ = the commitment liberation rate for

consumers of fuel n in sector m
$_mD_n$ = the demand for fuel n by sector m

That is, the market sensitive demand of sector m (MDS_m) equals the sum of the incremental demand (ID_m) and the replacement demand (RD_m) for that sector.

The incremental demand for the total sector (ID_m) is simply the sector rate of growth (RG_m) multiplied by the total sector demand (TD_m) in the given year. For each primary consuming sector the rate of growth (RG_m) is an exogenous input and equal to the average rate of growth that existed for that sector in the period 1945-70. Therefore, the incremental demand for each primary sector is an exogenous input to the model.

The replacement demand for sector m (RD_m) is determined by the summation of the products of the consumer commitment liberation rates for fuel n ($_mCLRT_n$) and the current consumption of fuel n in sector m ($_mD_n$). The concept of commitment liberation rates as employed in the 'Canadian Interfuel Substitution Model' is very broad. Since the notion of the commitment liberation rate, as used here, is synonymous with the rate at which consumers unlock past commitments to enter the marketplace, it is obvious that possible reasons for unlocking past commitments would include physical depreciation of equipment, economic benefits, technological obsolescence and convenience. In the model, the consumer commitment liberation rates ($_mCLRT_n$) are exogenous inputs.

2. CALCULATION OF DISTRIBUTION MULTIPLIERS

The function that the distribution multipliers perform in each demand sector is to determine what fraction of the sector's free demand is satisfied by each fuel form in each time period.

There are several functional forms which may be used to represent the distribution multipliers. Regardless of which functional form is accepted, there are two general constraints which must be satisfied by the distribution multipliers within each demand sector. First, all of the distribution multipliers must be non-negative and secondly, the sum of all the distribution multipliers within any given demand sector must equal 1.0 for every time period.

Only two functional forms for the distribution multipliers will be discussed here. These two forms will be referred to as the Baughman functional form and the Modified-Khazzoom functional form. The attempts to derive distribution multipliers for the Canadian Interfuel Substitution Model assumed that these functions were strictly economic functions in that they could adequately be represented by price variables alone.

The Baughman functional form[1], which was discarded as

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[1] Martin Baughman, _Dynamic Energy System Modeling - Interfuel Competition,_ Report #72-1, Energy Analysis and Planning Group, School of Engineering, M.I.T., Cambridge, Mass. August 1972, p. 63.

an acceptable form for the Canadian Interfuel Substitution Model, is justified primarily on the basis of one of its characteristics. The distribution multipliers were constrained by definition to be non-negative since Baughman's functions were represented by log-linear relationships. The structure of the Baughman distribution multipliers for each demand sector are as follows:

$$\ln(\underline{d}) = (\underline{A} \times \underline{P}) \tag{III.4}$$

where
$\ln(\underline{d})$ = natural logarithm of $\underline{d}$
$\underline{d}$ = n x 1 matrix of distribution multipliers
n = number of fuel forms available
$\underline{A}$ = n x n matrix of price coefficients, all values are assumed to be constant.
$\underline{P}$ = n x 1 matrix of fuel prices.

Re-arranging equation III.4 yields,

$$\underline{d} = \underline{c}\mathrm{EXP}(\underline{A}\mathrm{x}\underline{P}) \tag{III.5}$$

where
$\underline{c}$ = n x 1 matrix of constants.
$\mathrm{EXP}(\underline{A}\mathrm{x}\underline{P})$ = exponent of $(\underline{A}\mathrm{x}\underline{P})$

In order to ensure that the sum of the distribution multipliers is 1.0, Baughman divided the initial estimates by their sum for each time period. This, in effect, normalizes the initial estimate and guarantees that the sum of the distribution multipliers will be 1.0.

Unfortunately, the validity of the Baughman functional form, as it applies to the Canadain situation, came under serious questioning after parameter estimation studies were conducted. The signs of most of the estimated parameters were different from those that were predicted by simple economic theory. In addition, many of the parameter estimates were found to be insignificantly different from

zero in a statistical sense. For these reasons it was decided to reject the Baughman functional form and search for a more appropriate form to suit the Canadian Interfuel Substitution Model.

The work completed by Khazzoom (11,12) suggests that the interfuel decision process is more accurately depicted by a comparison of the relative fuel prices rather than a comparison of the absolute fuel prices as suggested by Baughman. As a result of Khazzoon's findings an attempt was made to represent the distibution multipliers as polynomial functions of the relative fuel prices. This functional form is referred to as the Modified-Khazzoom functional form. It was clear from the results of the initial parameter estimates of the Modified-Khazzoom functional form that the decision criterion for allocating free demand was dependent on more than simply the relative prices of fuels. In spite of this acknowledgement it was decided that a complete specification of the distribution multipliers would be a major undertaking which could not be justified within the framework of this thesis. Therefore, attempts were made to represent the non-price variations in the distribution multipliers with time series variables. This approach proved successful in most cases.

Thus, the Modified-Khazzoom distribution Multipliers for the Canadian Interfuel Substitution Model possess the following general structure:

$$\underline{m}d\underline{n}(t) = a\underline{0} + a\underline{1}\,[P\underline{n}RATIO(t)] + a\underline{2}\,[P\underline{n}RATIO(t)]^2 + a\underline{3}\,[TIME] \qquad (III.6)$$

where $\underline{m}d\underline{n}(t)$ = the distribution multiplier for fuel $\underline{n}$ in sector $\underline{m}$
$a\underline{k}$ = estimated parameters of independent variables. $\underline{k}$ = 0,1,2,3.
$P\underline{n}RATIO(t)$ = the ratio of the price of fuel $\underline{n}$ to the geometric mean of other fuel prices.
TIME = time series variable.

As a result of the success achieved in estimating the parameters for the Modified-Khazzoom functional form with the additional time series variables, these distribution multipliers[1] were accepted for use in the Canadian Interfuel Substitution Model. One unavoidable drawback of these functions was the necessity of imposing, in an 'artificial' manner, the non-negative and unity constraints of the distribution multipliers. The non-negative constraint was satisfied by equating the value of the distribution multiplier to either its initial estimate or zero - whichever is larger. The unity constraint was satisfied by employing the same normalizing process which Baughman used.

3. DETERMINATION OF CURRENT SECTOR DEMAND BY EACH FUEL

In the simulation of the primary energy demand sectors the determination of the current sector demand for each fuel represents the final step for any given time period. Here, the cumulative results of earlier calculations are summarized as the 'updated' estimates of the sector-by-

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[1] refer to Appendix E for complete derivation of the Modefied-Khazzcom functional form and the corresponding statistical results of parameter estimation.

sector demands for each energy form are presented.

The structural form from which these new estimates are calculated for the primary energy demand sector is as follows:

$$\frac{d[\underline{m}D\underline{n}(t)]}{dt} = -[\underline{m}RD\underline{n}(t)] + [\underline{m}d\underline{n}(t) \times MSD\underline{m}(t)] \qquad \text{(III.7)}$$

where
- $\underline{m}D\underline{n}$ = the demand for fuel $\underline{n}$ by sector $\underline{m}$
- $\underline{m}RD\underline{N}$ = the replacement demand for fuel $\underline{n}$ in sector $\underline{m}$
- $\underline{m}d\underline{n}$ = the distribution multiplier for fuel $\underline{n}$ in sector $\underline{m}$
- $MSD\underline{m}$ = the market sensitive demand in sector $\underline{m}$

Therefore, the instantaneous rate of change of demand for fuel $\underline{n}$ by sector $\underline{m}$ at time t is equal to the replacement demand for fuel $\underline{n}$ in sector $\underline{m}$ subtracted from the proportion of market sensitive demand which is allocated to fuel $\underline{n}$ in sector $\underline{m}$. Clarification of this equation will be given later in this chapter when a detailed description of the Residential and Commercial demand sector equations will be presented. By integrating this equation over time it is possible to obtain the level of demand for fuel $\underline{n}$ in each sector $\underline{m}$.

Thus, the operation of the model as it simulates the interfuel substitution process of the primary demand sectors may be summarized as follows. First, the values of the exogenous varibles for each sector are determined. The exogenous variables are the total sector energy demand, rate of growth of total sector demand, individual fuel prices and

the consumer's commitment liberation rate for each fuel. With this information the model calculates the total market sensitive (free) demand for each sector; converts this free demand through the distribution multipliers into demand for particular fuel forms and then estimates the current sector demand for each fuel.

However, as mentioned earlier, the electricity generating sector is a special case since it consumes energy, produces energy and has more fuel forms available to it than any other sector. The electricity generating sector receives, as output from the primary consuming sectors, the total and incremental demands for electricity. The quantities of electricity produced from hydro and nuclear power are given as exogenous inputs to the model. With this information the model is able to determine what proportion of the free demand is satisfied by fossil fuels. Then, the calculations proceed in much the same manner as for the primary consuming sectors to determine the electricity generating sector's demand for each of the fossil fuels.

Having completed a general description of the structures of the primary demand sub-models and the electricity generating sub-model, a detailed description of one of the primary demand sub-models and the electricity generating sub-models will now be given.

For illustrative purposes, the residential and commercial space heating sub-model will be listed and

discussed in full detail[1]. The sub-model listing given below will be in mathematical notation.

RESIDENTIAL AND COMMERCIAL DEMAND SUB-MODEL

The residential and commercial demand is modeled as an exponential growth process. The rate of change of the sector demand is given by

$$\frac{d[RCD(t)]}{dt} = RCDRG \times RCD(t) \tag{III.8}$$

$$RCD(1945) = .38 \tag{III.9}$$

$$RCDRG = .071 \tag{III.10}$$

where RCD = the level of the residential-commercial demand initialized at .38 Q's[2] for the year 1945.

RCDGR = rate of growth of RCD modeled at 7.1% per year in the base case.

The rate of change of the consumption of fuel $\underline{n}$ in the residential-commercial sector is given by

$$\frac{d[RCD\underline{n}(t)]}{dt} = -RCD\underline{n}RD(t) + [RCDD\underline{n}(t) \times RCMSD(t)] \tag{III.11}$$

for $\underline{n}$ = W,X,Y,Z (coal, gas, oil and electricity respectively)

where $RCD\underline{n}(t)$ = the level of residential-commercial consumption of fuel $\underline{n}$ at time t.

$RCD\underline{n}RD(t)$ = residential-commercial replacement demand for fuel $\underline{n}$ at time t which also equals the rate of decline of consumption of fuel $\underline{n}$ if none of the market sensitive demand is supplied by fuel $\underline{n}$ at time t.

RCMSD(t) = residential-commercial market sensitive demand at time t.

$RCDD\underline{n}(t)$ = the residential-commercial demand distribution factor multiplying the market sensitive demand for each fuel at time t.

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[1] see Appendix C for complete listing of the model.

[2] one Q corresponds to 10^{15} BTU's.

The initial level of consumption for each of these fuels is

$$RCDW(1945) = .27\ Q's \qquad \text{(III.12)}$$
= initial sector demand for coal.

$$RCDX(1945) = .02\ Q's \qquad \text{(III.13)}$$
= initial sector demand for natural gas.

$$RCDY(1945) = .03\ Q's \qquad \text{(III.14)}$$
= initial sector demand for crude oil.

$$RCDZ(1945) = .06\ Q's \qquad \text{(III.15)}$$
= initial sector demand for electricity.

The replacement demands are given by

$$RCD\underline{n}RD(t) = RCD\underline{n}(t) \times RC\underline{n}B \qquad \text{(III.16)}$$

for $\underline{n}$ = W, X, Y, Z.

where RCD$\underline{n}$RD = the residential-commercial replacement demand for fuel $\underline{n}$.
RC$\underline{n}$B = the commitment liberation rate for consumers of fuel $\underline{n}$.

The residential-commercial market sensitive demand is the sum of the incremental demand and replacement demands; it can be written as

$$RCMSD(t) = [RCDRG \times RCD(t)] + \sum_{\underline{n}} RCD\underline{n}RD(t) \qquad \text{(III.17)}$$

where RCMSD(t) = residential-commercial market sensitive demand at time t.

The distribution multipliers are calculated in a two-step procedure. First the initial estimates are computed, then they are normalized so their sum is equal to unity. This is in line with the assumption that total consumption in each consuming sector is inelastic. First, the estimates are given by

$$RCDD\underline{n}1(t) = a\underline{n}\underline{0} - [a\underline{n}\underline{1} \times P\underline{n}RATIO(t)] + [a\underline{n}\underline{2} \times P\underline{n}RATIO(t)^2]$$
$$+ [a\underline{n}\underline{3} \times TIME] \qquad (III.18)$$

for $\underline{n}$ = W,X,Y,Z.

where RCDD$\underline{n}$1 = initial estimate of the distribution multiplier for fuel $\underline{n}$ at time t.
a$\underline{nk}$ = estimated coefficients for distribution multiplier of fuel $\underline{n}$ for $\underline{k}$ = 0,1,2,3.
P$\underline{n}$RATIO(t) = ratio of the price of fuel $\underline{n}$ to the geometric mean of the fuel prices of the other three fuels at time t.
TIME = time in years initialized at 1945.

The sum of these initial estimates is given by

$$RTOTAL(t) = \sum_{\underline{n}} RCDD\underline{n}1(t) \qquad (III.19)$$

and the normalized distribution multipliers are given by

$$RCDD\underline{n}(t) = RCDD\underline{n}1(t) \;/\; RTOTAL(t) \qquad (III.20)$$

for $\underline{n}$ = W,X,Y,Z.

where RCDD$\underline{n}$(t) = the normalized distribution multiplier which is used to allocate the free (market sensitive) demand at time t.

Therefore, the above are the basic equations for the residential and commercial demand sub-model.

ELECTRICITY GENERATING SUB-MODEL

The electricity generating sub-model is quite similar, in structure, to that just described for the primary consuming sectors. However, besides generating electricity from the fossil fuels, the model must take into account the role of the nuclear and hydro generation. The additional electrical power generated by nuclear and hydro sources in each time period is an exogenous input. Therefore, the quantity of market sensitive demand which is satisfied by hydro and nuclear sources in each time period is predetermined. Once the market sensitive demand is

determined endogenously, the quantity of electricity which must be generated from fossil fuels is calculated by subtracting the incremental hydro and nuclear generation from the total market sensitive demand. Then, the choice of fossil fuel mixes is made in the same manner as in the primary demand sectors. The market sensitive demand for the electricity generating sector is simply the sum of the incremental demand for electricity of the primary demand sectors and the replacement demand of the fossil generated electricity.

The incremental electricity demand can be written as

$$ZDG1(t) = \sum(\text{increments in electrical consumption from each primary consuming sector}) \quad (III.21)$$

where ZDG1(t) = the incremental electricity demand at time t.

The fossil fuel replacement demands are given by

$$ZF\underline{n}RD(t) = ZF\underline{n}(t) \times ZF\underline{n}B \quad (III.22)$$

for $\underline{n}$ = W, X, and Y.

where $ZF\underline{n}RD(t)$ = the replacement demand in electricity for fossil fuel $\underline{n}$ at time t.
$ZF\underline{n}(t)$ = the quantity of total electrical output supplied by fuel $\underline{n}$ at time t.
$ZF\underline{n}B$ = the commitment liberation rate for consumers of fuel $\underline{n}$ in the electricity generating sector.

The fraction of electrical output supplied by nuclear power is assumed to be the same as the fraction of total capacity made up of nuclear power.

$$ZFN(t) = [1.0 - FCF(t)] \times ZO(t) \quad (III.23)$$

where ZFN(t) = the electical output produced from nuclear generation (Q's/year) at time t.
FCF(t) = the fraction of capacity made up of fossil fuel and hydro plants at time t.

ZO(t) = total electrical output at time t.

The electrical output produced from hydro generation (ZFH) is exogenously fed into the model via a Dynamo table function.

The fossil incremental demand is derived by subtracting the increments in nuclear and hydro output from the total growth in electrical output. This is written as

$$ZFFG(t) = ZDG1(t) - (\Delta ZFN(t)/\Delta t) - (\Delta ZFH(t)/\Delta t) \qquad (III.24)$$

where ZFFG(t) = the growth in electrical output to be supplied by fossil fuels at time t.
ZDG1(t) = the total growth in electrical output at time t.
$\Delta ZFN/\Delta t$ = the growth in output supplied by nuclear generation.
$\Delta ZFH/\Delta t$ = the growth in output supplied by hydro generation.

The fossil market sensitive demand is then the sum of the fossil incremental demand and the fossil replacement demand, or

$$ZFSD(t) = ZFFG(t) + \sum_{\underline{n}} ZF\underline{n}RD(t) \qquad (III.25)$$

where ZFSD(t) = the fossil market sensitive demand at time t.
ZFFG(t) = the fossil incremental demand at time t.
$ZF\underline{n}RD(t)$ = the replacement demand of fuel $\underline{n}$ at time t.

It is possible that a shift from fossil generation to hydro or nuclear generation may occur, in which case ZFFG(t) in Equation III.24 would be negative.

The dynamics of the fossil fuel demands in electricity are now given by the same equations as those for the primary demand sectors.

The consumption of the primary fuels (in Q's) in

electricity generation is easily obtained from the equations

$\underline{n}TOZ(t) = [ZF\underline{n}(t) \times HRF(t)]/(.0094)$ (III.26)

for $\underline{n}$ = W,X,Y.

where $\underline{n}TCZ$ = the consumption of fuel $\underline{n}$ in the electricity sector at time t.
$ZF\underline{n}(t)$ = the output of electricity produced by fuel $\underline{n}$ at time t.
HRF(t) = the fossil heat rate in millions of BTU's per kilowatt-hour at time t. The same heat rates that Baughman used were assumed here.
.0094 = the lossless conversion rate in millions of BTU's per kilowatt-hour.

This concludes the description of the electricity generating sector. Although only the residential-commercial demand sector and the electricity generating sector were described in detail here, a complete listing of the total model is available in Appendix C[1].

The task of transforming the qualitative theory of interfuel substitution into a corresponding quantitative form is complete. The final stage in the development of the Canadian Interfuel Substitution Model consists of testing the validity of the mathematical model.

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[1] the listing in Appendix C is given in Dynamo (21) format.

C. MODEL VALIDATION

The problem of validating mathematical models in the social sciences is very complicated and it has received little attention in the past.

First, we must have a clear understanding of the term 'validity'. Many social scientists have implicitly accepted the concept of validity that equates 'valid' with 'true'. When applied to mathematical models, this approach has several drawbacks. It is improper to consider these models in such strong terms as being either true or false. A social model can never be proven unconditionally true. In addition, this approach fails to recognize the benefits gained from constructing the model by over-emphasizing the final results.

Probably the most satisfactory definition of the term validity in the context of the Canadian Interfuel Substitution Model is:

> A model is valid if it is useful for a clearly stated purpose. And, for causal descriptive models, a purpose calls for a model which describes reality with sufficient accuracy to be useful for investigating alternative social policies[1].

With this definition in mind, an outline of the model validation procedure can be described. Generally speaking,

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[1] Peter M. Senge "Some Issues in Evaluating the Validity of Social System Models", Proceedings of the Summer Computer Simulation Conference (Montreal 1973), p. 1176.

two broad categories of model testing techniques exist: the tests of whole model behavior (Macro tests) and tests related to the structural components (Micro tests). Within each category there are several tests which may be employed. An exhaustive validation procedure was not implemented due to time constraints although the tests conducted here are considered sufficient.

MACRO TESTS

i. Basic Assumptions of Model Structure

Under this heading the basic assumptions underlying the model structure are examined and if they are unacceptable the necessary changes are made.

ASSUMPTION I: Energy consumer decisions can be adequately modeled when the levels of aggregation are such that there exist four national sources of energy demand (transportation, residential and commercial, industrial and electricity generation) which are satisfied by four forms of energy fuels (crude oil, natural gas, coal, and electricity).

It is obvious from the historical data that Canadian energy consumption patterns have varied widely from one geographic region to another. However, the only consequence of this fact is to place limitations on the conclusions and recommendations that may be derived from the model.

The levels of aggregation used in the model present no

difficulties for model validation if the information extracted from the model is on a corresponding level of aggregation.

ASSUMPTION II: In the model there has been no explicit consideration of the possibilities of technological changes which may introduce new fuel forms (i.e. solar energy) or perhaps even create new demand sectors. Although these unaccounted possibilities are particularily important for long range projections, they are not considered to be significant for the 15 year projection span used in this study.

MICRO TESTS

i. Data Base Validation

The data base for the model was double checked in search of possible errors and problems of inaccuracy or misinterpretations.

Although several problems do exist in the raw data, the necessary corrections and adjustments were made to make the data and the model structure compatible. A full description of this data base and the associated problems is given in Appendix A.

ii. Basic Assumptions of Structural Components

ASSUMPTION I: The commitment liberation[1] rates of consumers are exogenous inputs into the model and they have assumed values since no data are available for these values. With the exception of two cases (IHWB,TRWB), these values are considered constants and they have rather small values ($\leq .20$) according to intuitive judgement.

Generally, it is agreed that the longer a fuel has been consumed in significant quantities, the higher will be the potential commitment liberation rate of consumers using this fuel. For this reason, the commitment liberation rates of coal consumers have been very high while those of gas consumers are still relatively low.

The commitment liberation rates used in the model are believed to adequately represent past behavior. However, problems do arise when providing future expected values of these commitment liberation rates for model projections.

ASSUMPTION II: The fuel prices at the production sites (coal mines, gas fields, etc.) are sufficiently correlated with the retail fuel prices so that they may be used as the prices that consumers respond to.

Of all the assumptions made, this one appears to be the most questionable. Large fluctuations in retail fuel prices

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[1] as defined earlier, the commitment liberation rates of consumers refer to the rates at which consumers unlock their past committments to particular fuel forms.

do exist from one geographic region to another. In addition, there are several cases where it is a foreign fuel price that consumers are responding to (USA coal imported to Ontario, foreign crude oil imported to Eastern Canada). Although this later point is important when examining the determinants of price levels and price changes, it is much less significant when examining only the impact of these prices on demand since the foreign fuel and domestic fuel prices and fluctuations have been very similar since 1945.

In spite of the undesirability of this assumption concerning fuel prices, it was made in order to simplify the model. As long as this simplification does not lead to gross inaccuracies or misuses of the model it is considered acceptable.

ASSUMPTION III: The nuclear and fossil heat conversion rates are the same as those used by Baughman (1). Although they may be different for Canada, the difference is assumed to be negligible.

iii. 'Goodness of Fit' Tests

The area of model validation which has received the most attention in the past is that associated with 'goodness of fit' tests. It is under this heading that model builders describe, generally in a quantitative manner, the accuracy with which their model is able to reproduce past data.

Several quantitative tests that perform this task have been developed. The 'Canadian Interfuel Substitution Model'

was subjected to only three of these tests.

MEAN PERCENTAGE ERROR - This measure is simply the mean of all the percent errors that exist between the actual data and the model predictions. A problem with this measure exists in that a declining function will invariably have large percentage errors at its lower values even if the absolute errors remain unchanged. This produces an over-weighting of the errors at lower values of a function. The mathematical form of this measure is :

$$MPE = \left[\frac{1}{N} \times \left(\sum_{m=1}^{N} \frac{MODEL\underline{m} - ACTUAL\underline{m}}{ACTUAL\underline{m}}\right)\right] \times 100\% \qquad (III.27)$$

where N = the number of data sample points.

EQUATION VARIANCE - The equation variance is another measure of the dispersion of the actual data about the estimated model equation. The mathematical form of this measure is:

$$VAR = \frac{1}{N}\left[\sum_{m=1}^{N}(MODEL\underline{m} - ACTUAL\underline{m})^2\right] \qquad (III.28)$$

where N = the number of data sample points.

There is a tendency, with this statistic, to give more weighting to the larger model values since the absolute error is likely to be larger there.

R-SQUARED - Although this test statistic is really associated with the Ordinary Least Squates technique of estimating parameters for linear equations, it can be applied outside of this scope with the appropriate limitations. The purpose of this measure is to indicate what proportion of the variation of the data about its mean is described by the estimated equation. A value of R-Squared = 1.0 would indicate a perfect model fit while deviations from this value would indicate less than perfect fits. The mathematical form of this measure is:

$$R^2 = 1.0 - \left[\frac{\sum_{m=1}^{N}(MODEL\underline{m} - ACTUAL\underline{m})^2}{\sum_{m=1}^{N}(ACTUAL\underline{m} - MEANACT)^2}\right] \qquad (III.29)$$

where N = the number of data sample points.
MEANACT = mean of the actual data for the period 1945-70.

The R-Squared measure for goodness of fit is less suitable for rapidly changing, nonlinear (i.e. exponential) functions since that test statistic under these conditions will tend to give an over-optimistic impression of the goodness of

fit.

Since it is recognized that each of the test statistics described above has its own advantages and disadvantages, it is believed that an accurate measure of the goodness of fit would be obtained by using all three of these statistics.

The results of the goodness of fit tests are presented separately for the smoothing functions which were used to simulate the exogenous data of the model and the endogenous variables of the model. It is important to make this distinction when one is analyzing the source of model errors. In the case of the smoothed exogenous data of the model, the goodness of fit tests are applied to those functions which appear as estimated time series functions. The estimation errors that exist in these functions have direct effects on the final results of the model predictions. On the other hand, the errors that arise in the endogenously determined variables are the results of errors in the smoothing functions of the exogenous data coupled with the inability of the model to fully explain consumer behavior.

Table III.1 and Figures III.2 - III.3 present the results of the goodness of fit tests for the major smoothing functions of the exogenous data of the model.

Table III.2 and Figures III.4 - III.15 present the results of the goodness of fit tests for the major endogenous variables of the model.

At this point it must be mentioned that an explicit optimization procedure was not used to obtain the best fit of the model to the data. Rather, a trial and error approach was employed to minimize the errors and slight improvements are likely possible.

Figures III.16 - III.20 present the output of the Base Case which was not subjected to goodness of fit tests. The term 'Base Case' refers to the results of the model simulation for the period 1945-70.

TABLE III.1

'Goodness of Fit' Statistics for the Smoothing Functions of the Exogenous Data in the Model

Dependent Variable	Equation R^2	Equation Variance	Equation Mean Percentage Error
RCD	.9937	.0019	2.67
IHD	.9854	.0029	3.03
TRD	.9150	.0024	4.64

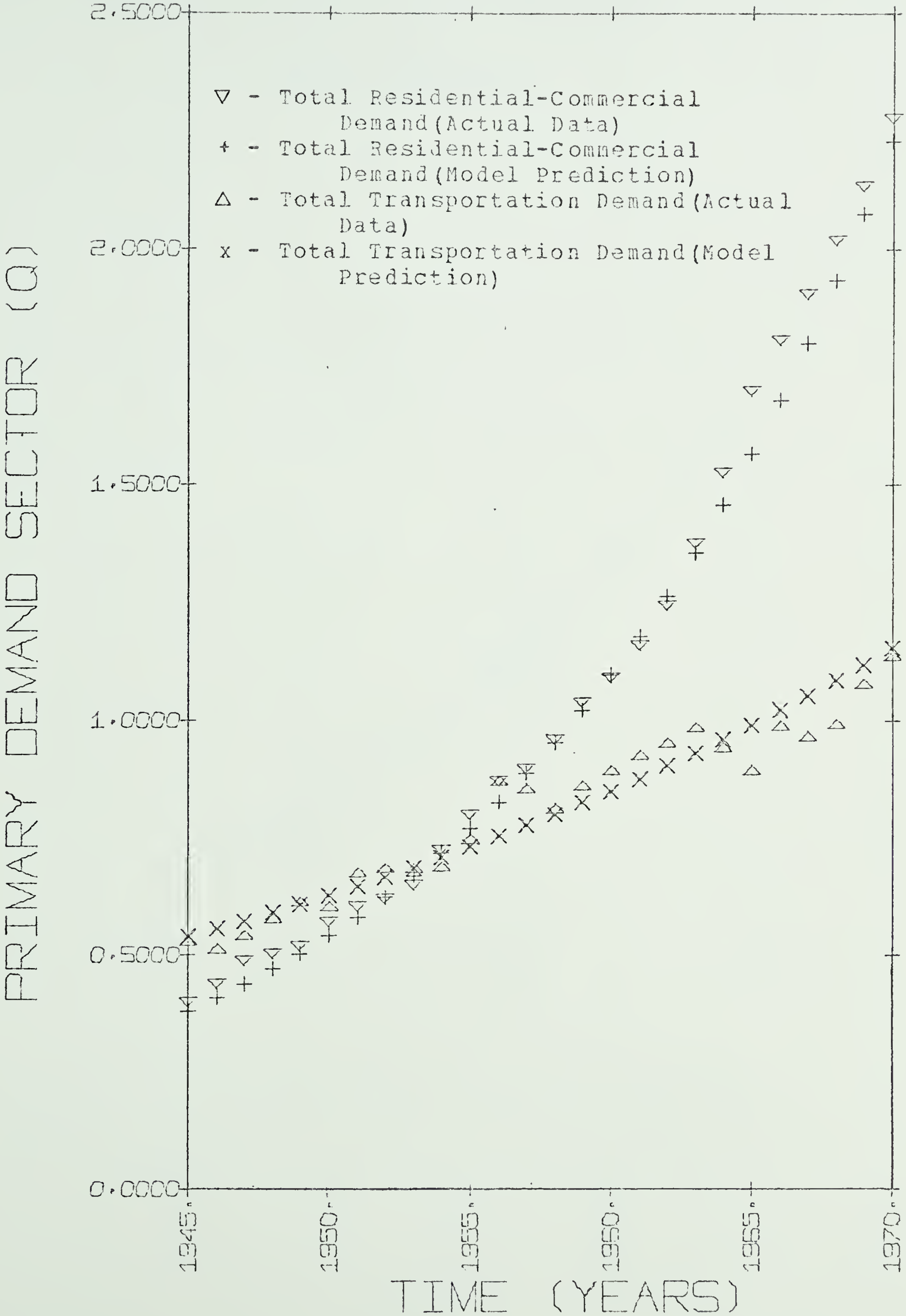

FIGURE III.2 - TOTAL ENERGY DEMAND BY RESIDENTIAL-COMMERCIAL AND TRANSPORTATION SECTORS, BASE CASE 1945-70.

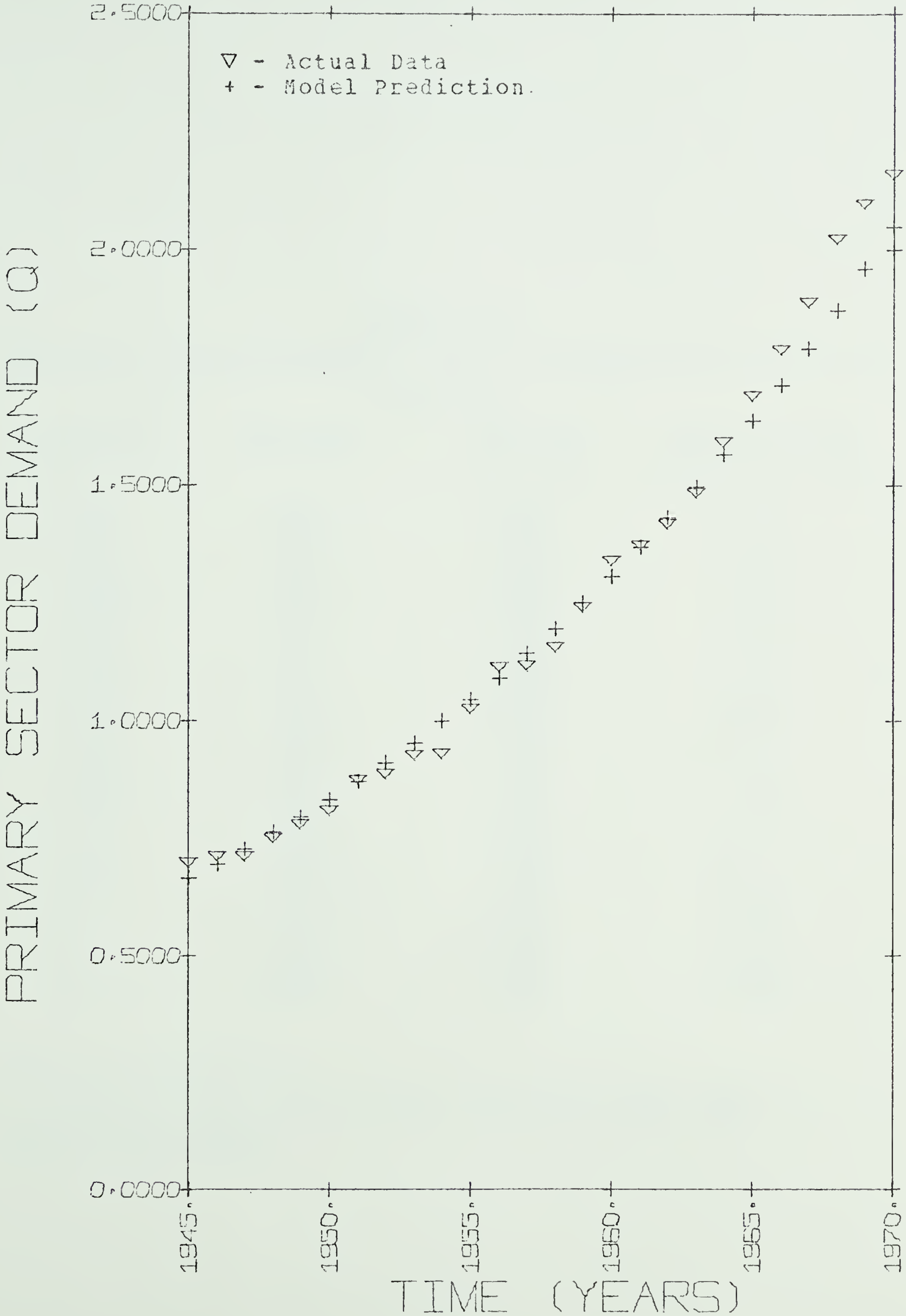

FIGURE III.3 - TOTAL ENERGY DEMAND BY INDUSTRIAL SECTOR, BASE CASE 1945-70.

TABLE III.2

'Goodness of Fit' Statistics for the Endogenous Variables in the Model

Dependent Variable	Equation R^2	Equation Variance	Equation Mean Percentage Error
TPEC	.9936	.0099	2.84
TED	.9955	.0065	1.73
RCDW	.9513	.0003	14.06
RCDX	.9957	.0000	7.34
RCDY	.9649	.0024	8.13
RCDZ	.9940	.0003	4.85
IHDW	.9468	.0002	4.83
IHDX	.9881	.0003	25.31
IHDY	.9456	.0010	11.40
IHDZ	.9821	.0007	2.77
TRDW	.9610	.0006	141.02
TRDY	.9548	.0039	6.06
ZFN	.8742	.0000	---- [1]
ZFW	.8501	.0010	43.79
ZFX	.6434	.0001	---- [1]
ZFY	.7310	.0001	44.76
WD	.9719	.0026	8.74
XD	.9921	.0007	13.95
YD	.9816	.0089	5.48
ZD	.9930	.0013	2.30

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[1] Meaningful estimates are not available since the percentage error is indeterminant for a large number of the sample data points.

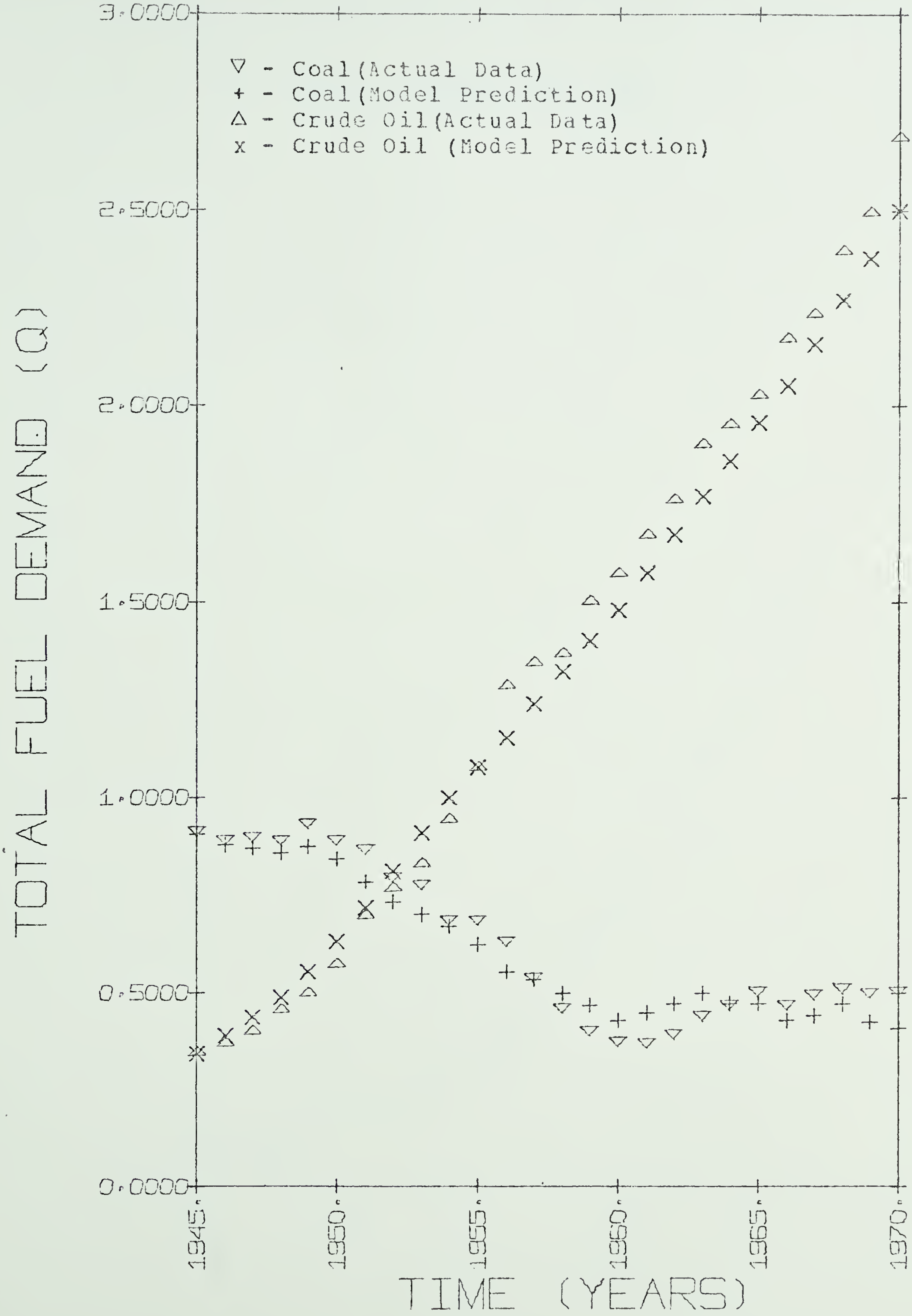

FIGURE III.4 - TOTAL DEMAND FOR CRUDE OIL (YD) AND COAL (WD), BASE CASE 1945-70.

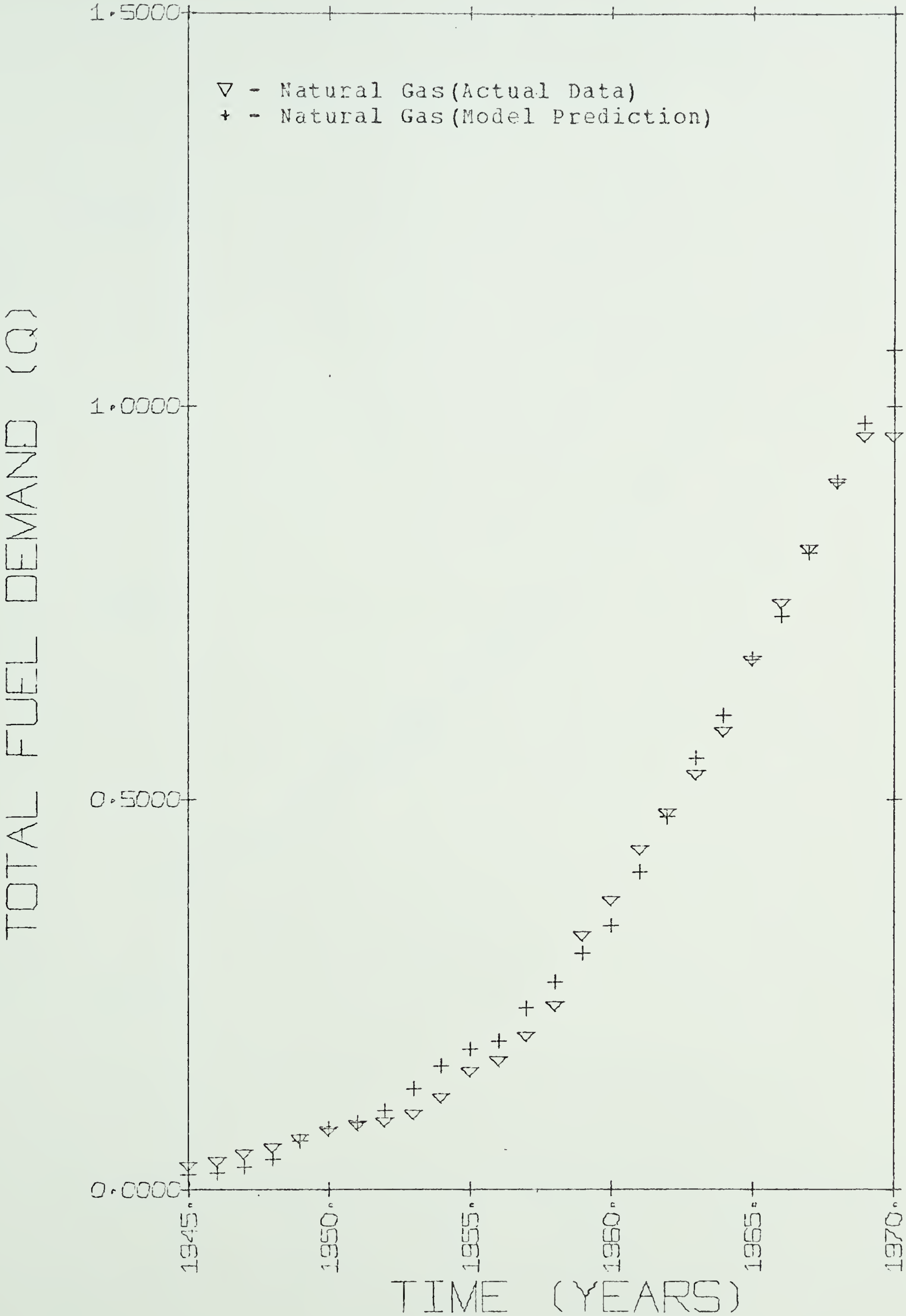

FIGURE III.5 - TOTAL DEMAND FOR NATURAL GAS (XD), BASE CASE 1945-70.

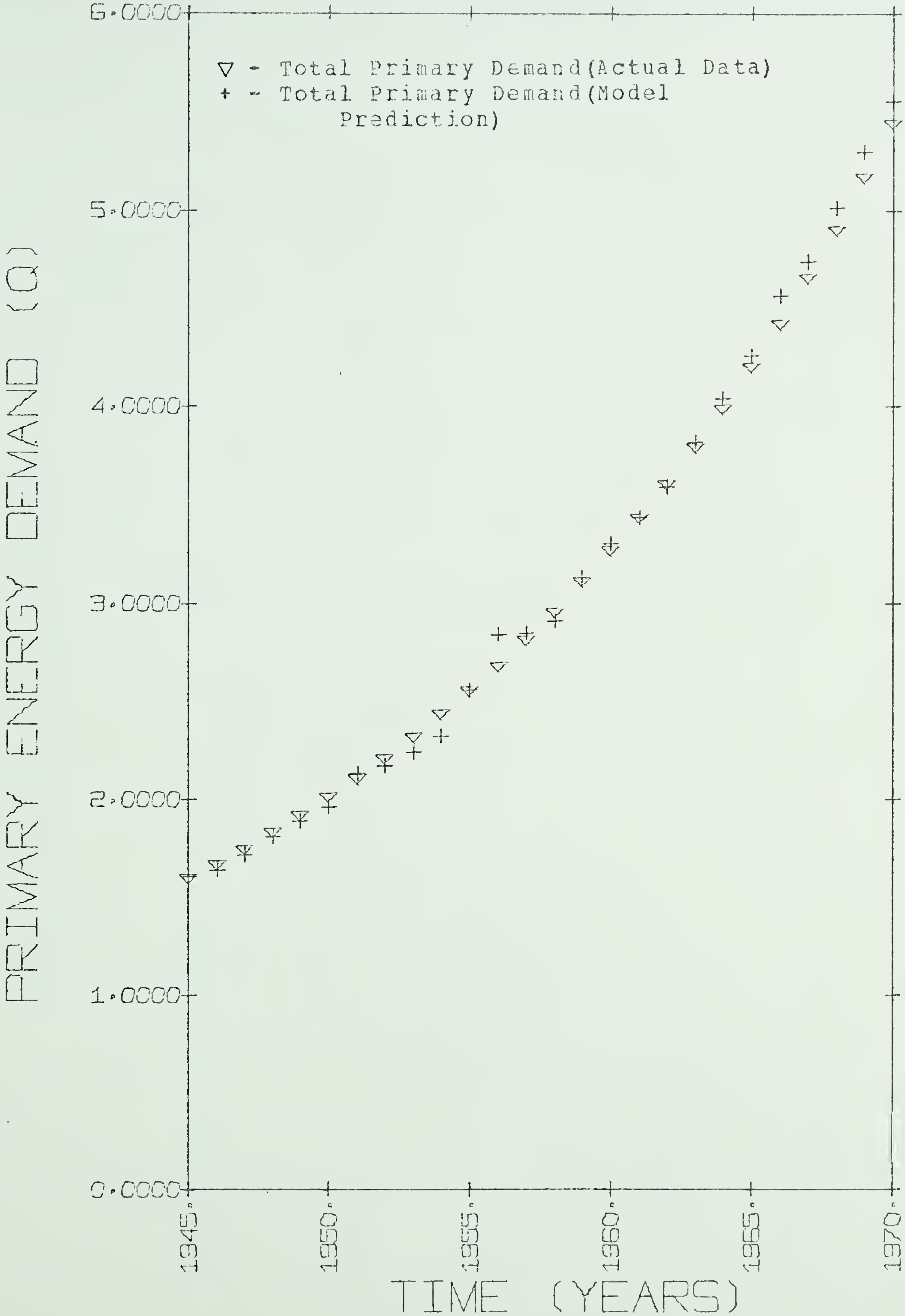

FIGURE III.6 - TOTAL ENERGY CONSUMPTION BY PRIMARY DEMAND SECTORS (TED), BASE CASE 1945-70.

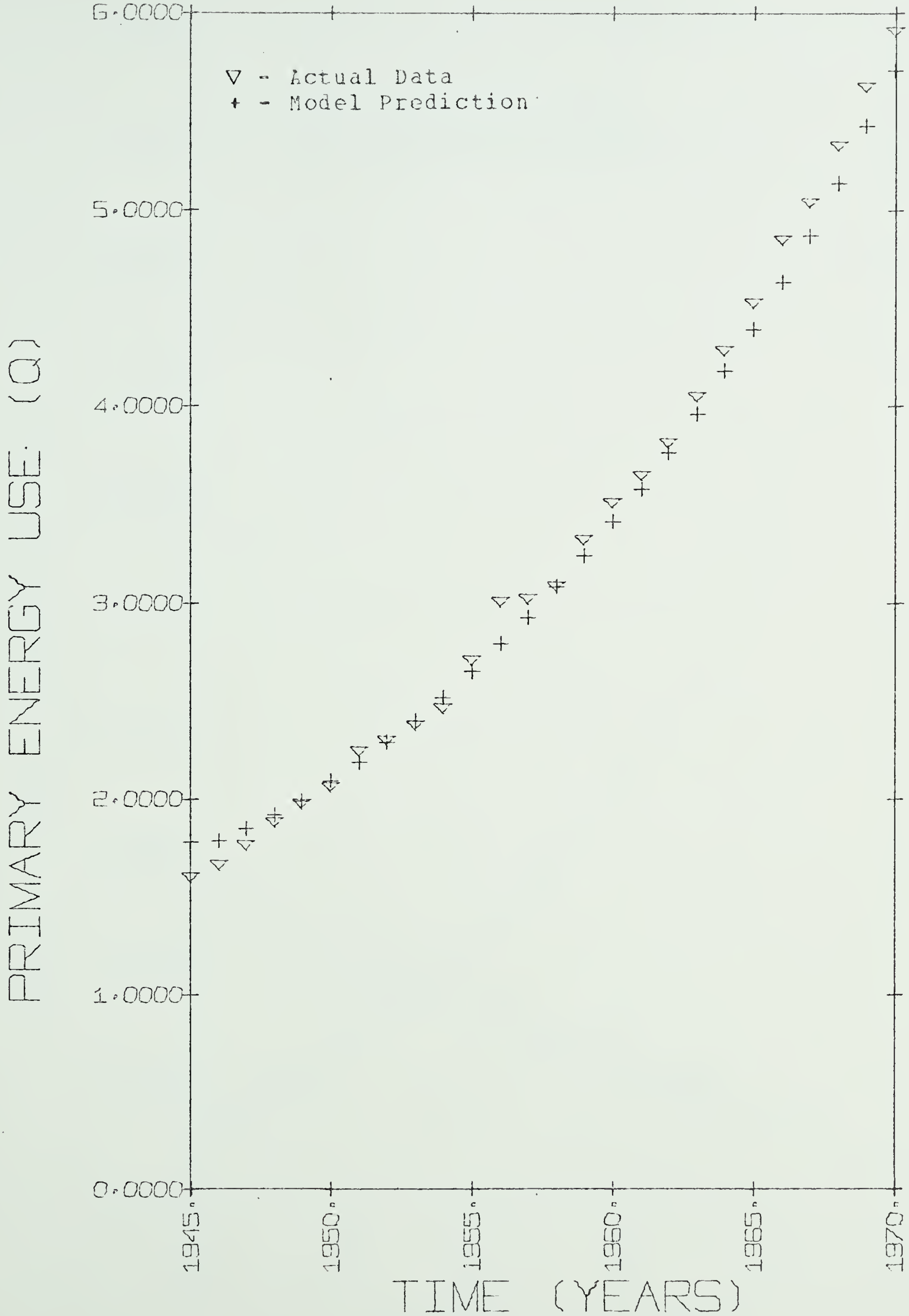

FIGURE III.7 - TOTAL CONSUMPTION OF PRIMARY ENERGY FORMS (TPEC), BASE CASE 1945-70.

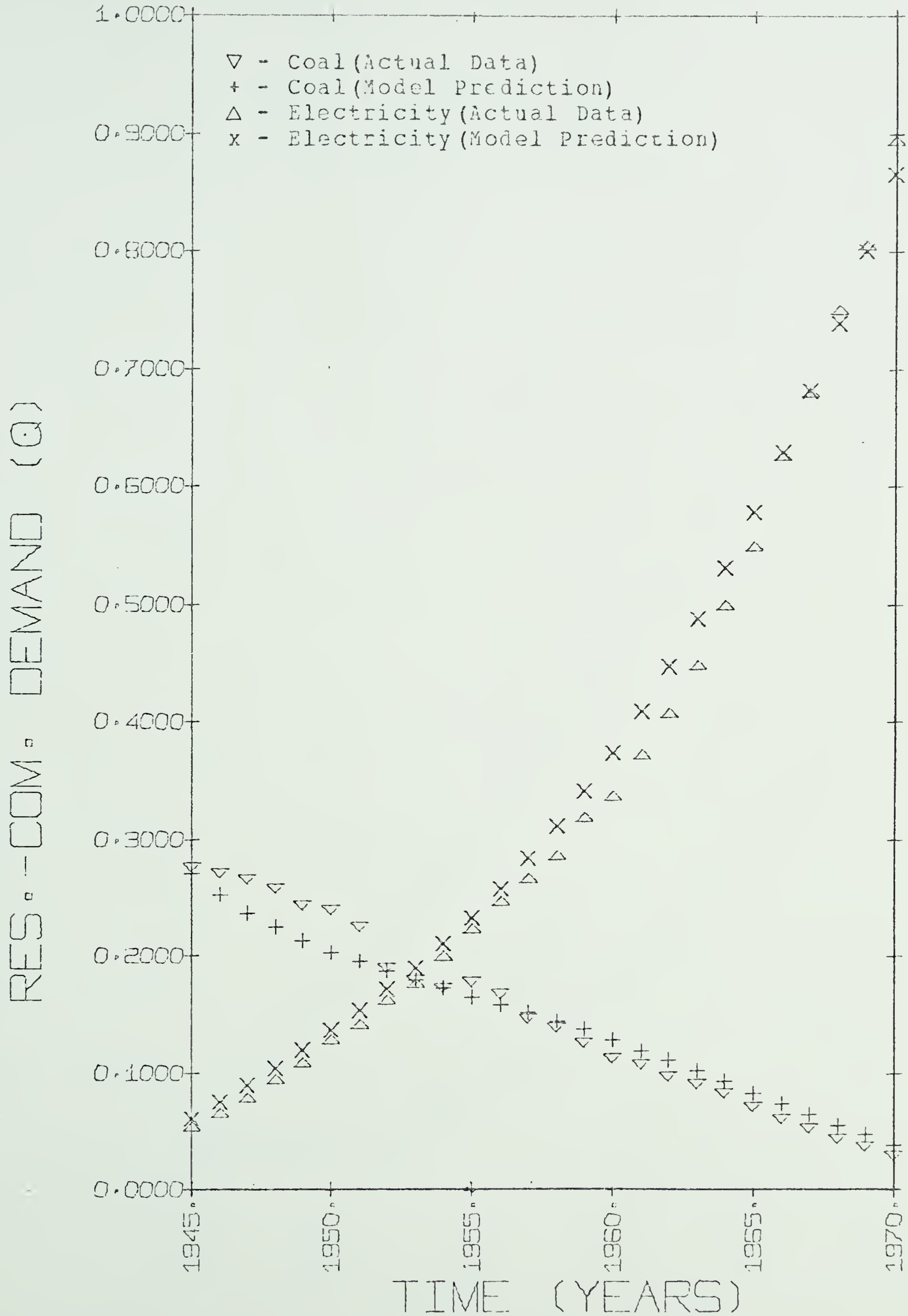

FIGURE III.8 - RESIDENTIAL-COMMERCIAL ENERGY DEMAND, BASE CASE 1945-70.

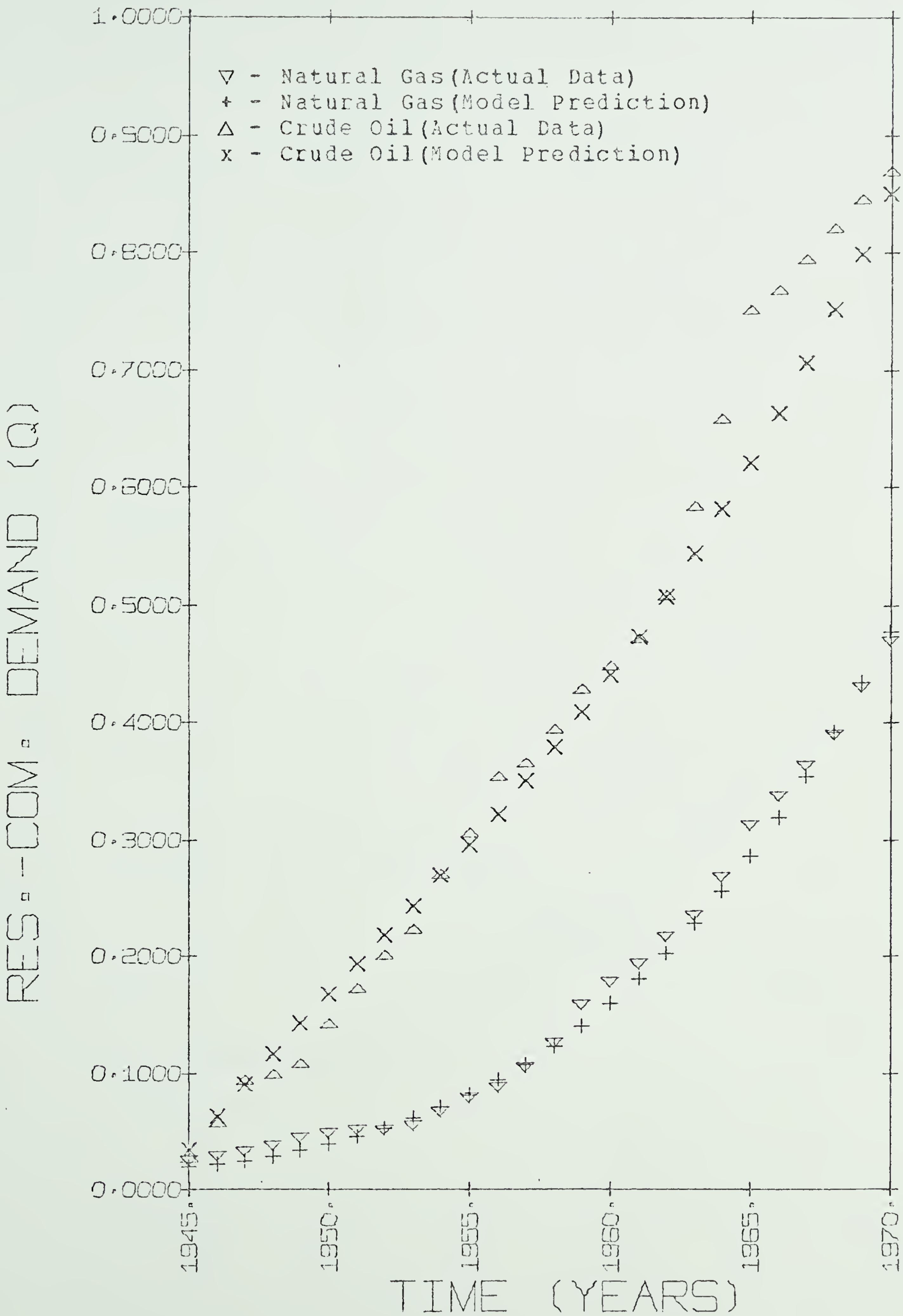

FIGURE III.9 - RESIDENTIAL-COMMERCIAL ENERGY DEMAND, BASE CASE 1945-70.

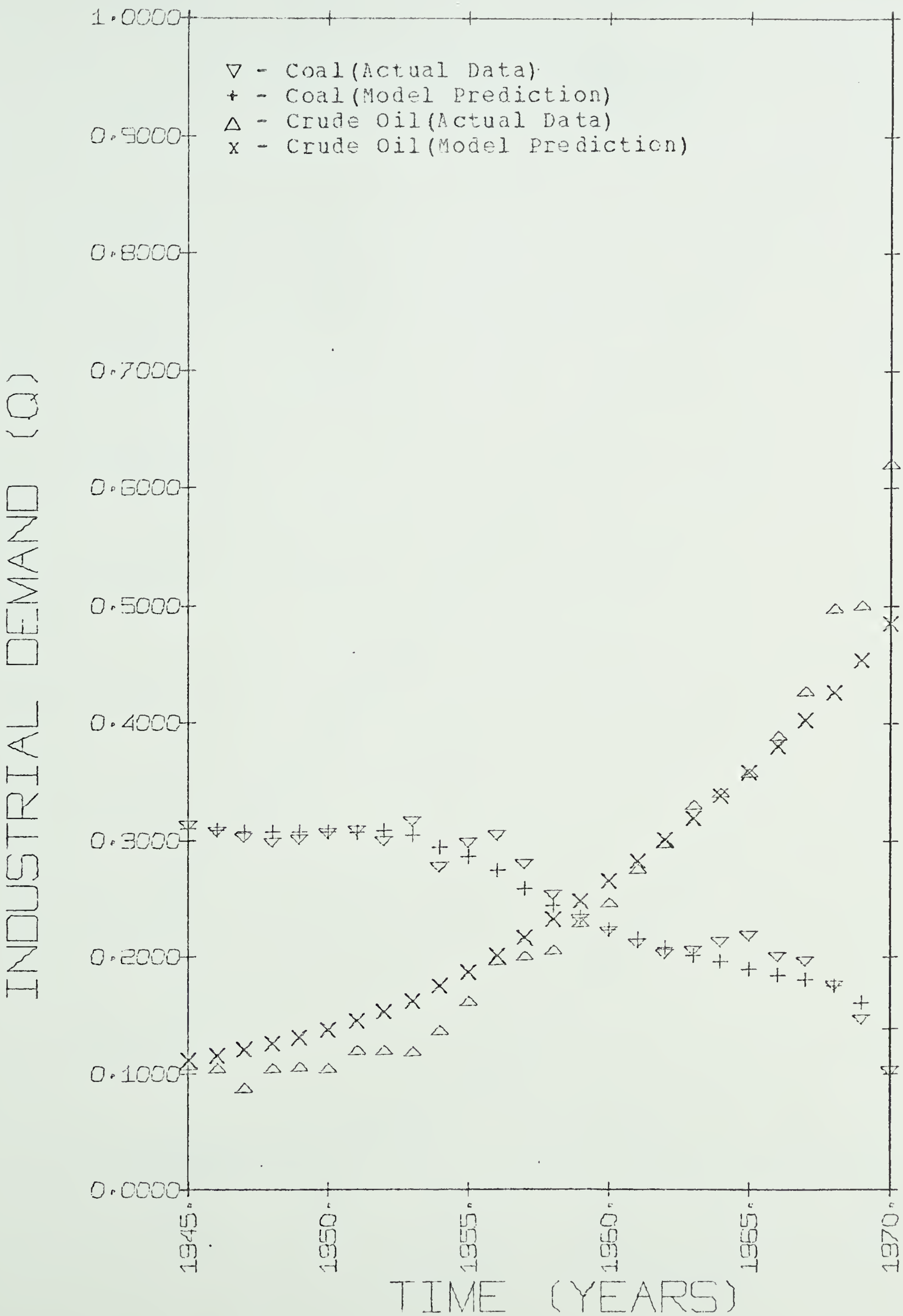

FIGURE III.10 - INDUSTRIAL ENERGY DEMAND, BASE CASE 1945-70.

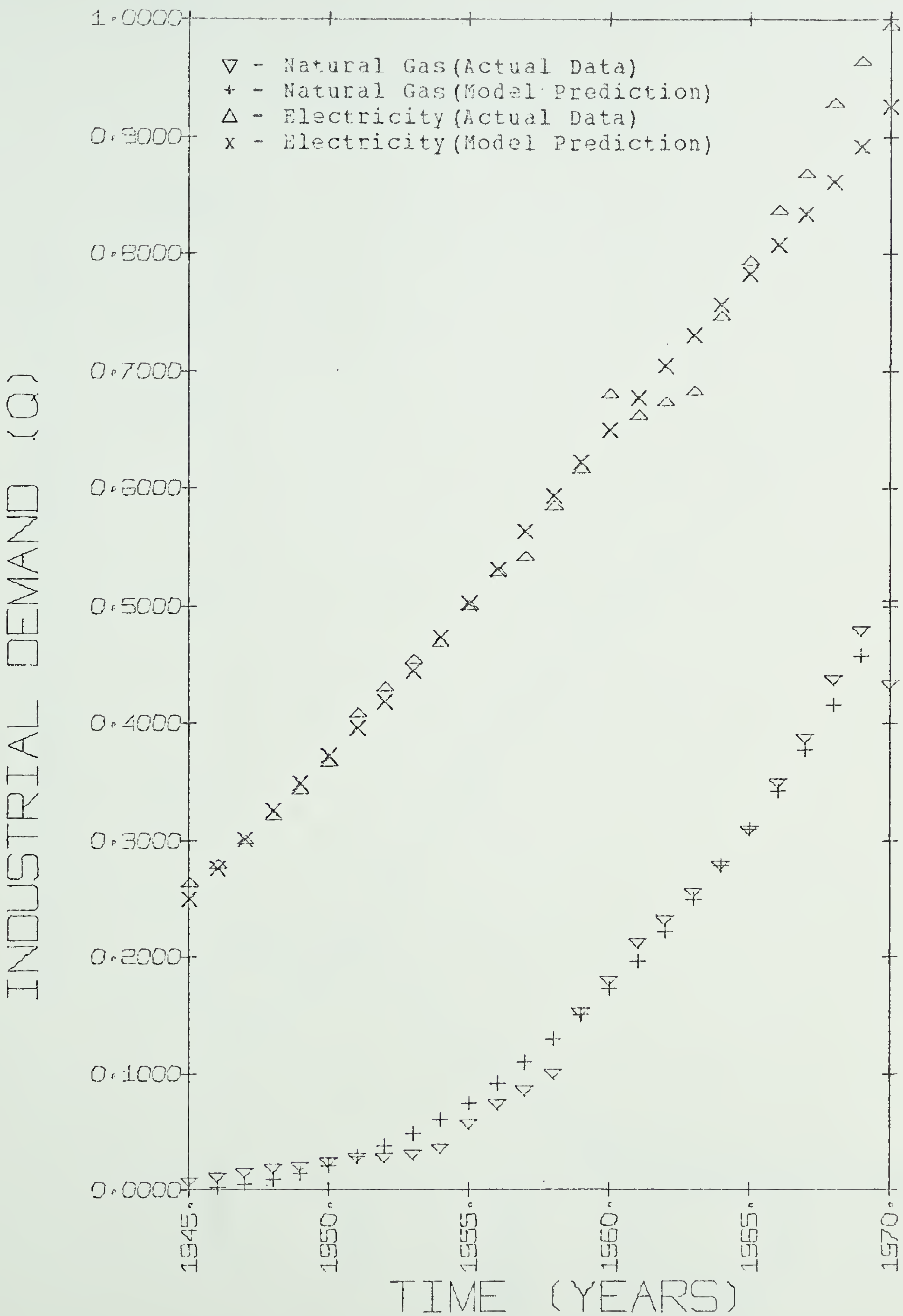

FIGURE III.11 - INDUSTRIAL ENERGY DEMAND, BASE CASE 1945-70.

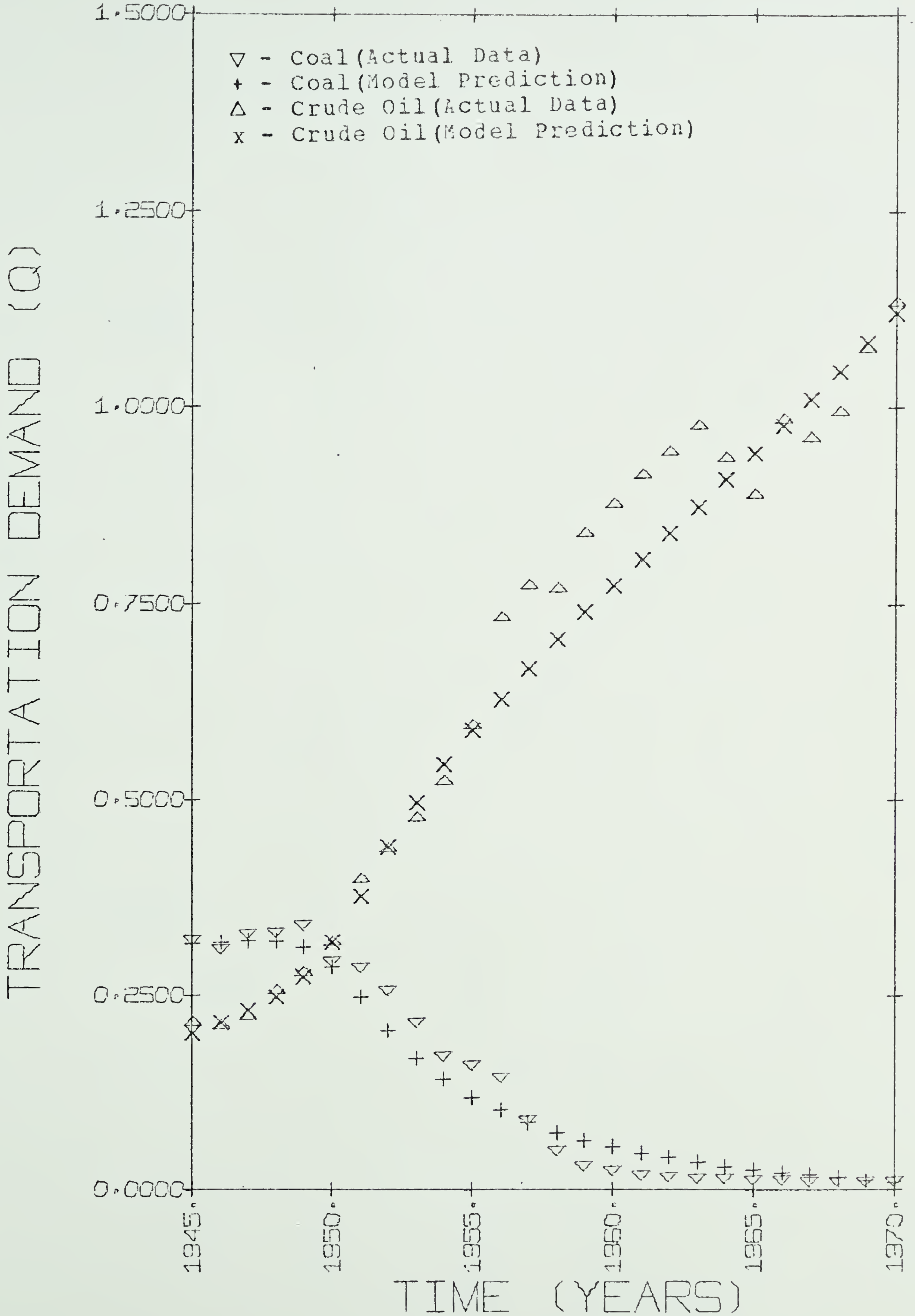

FIGURE III.12 - TRANSPORTATION ENERGY DEMAND, BASE CASE 1945-70.

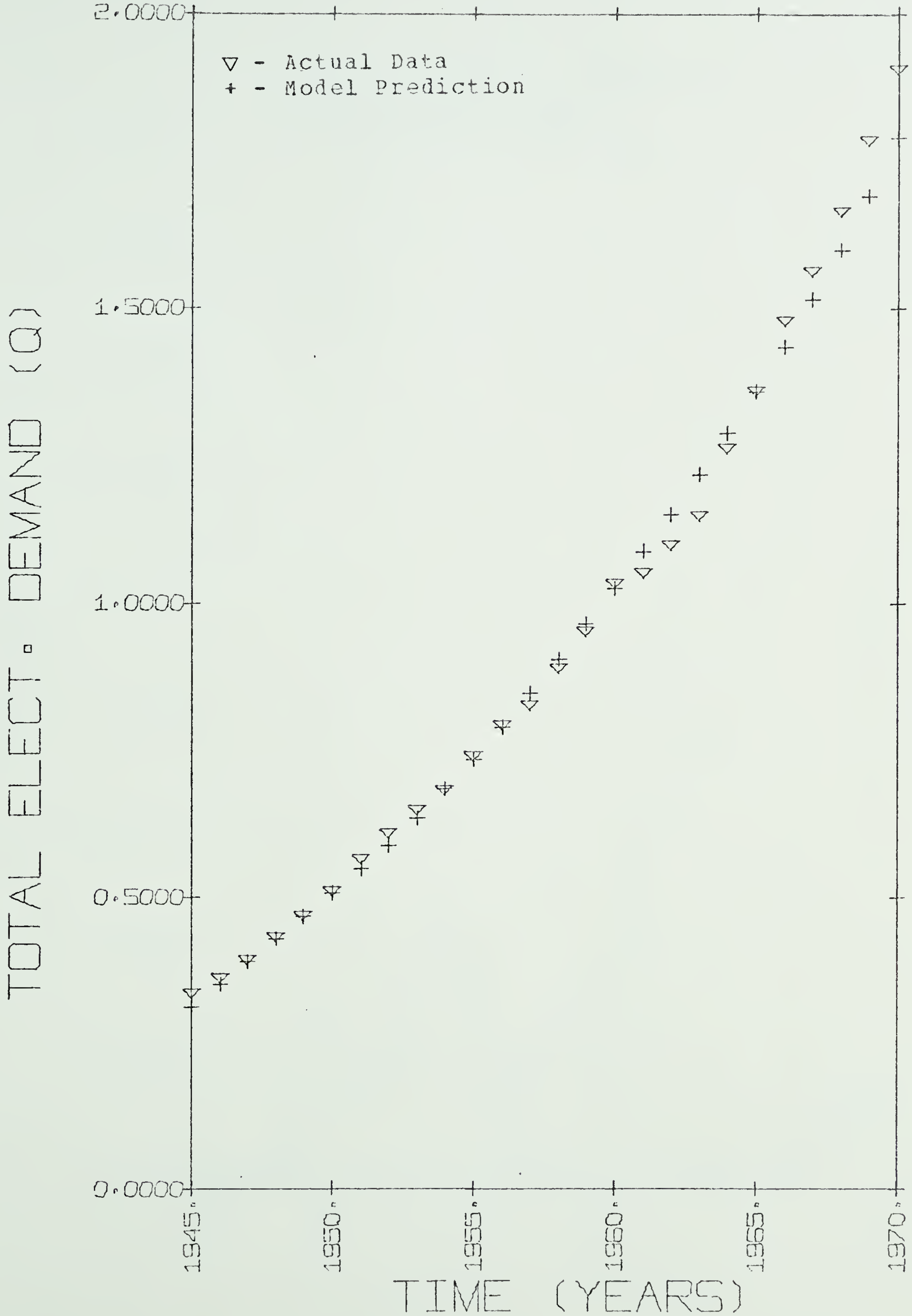

FIGURE III.13 - TOTAL DEMAND FOR ELECTRICITY (ZO), BASE CASE 1945-70.

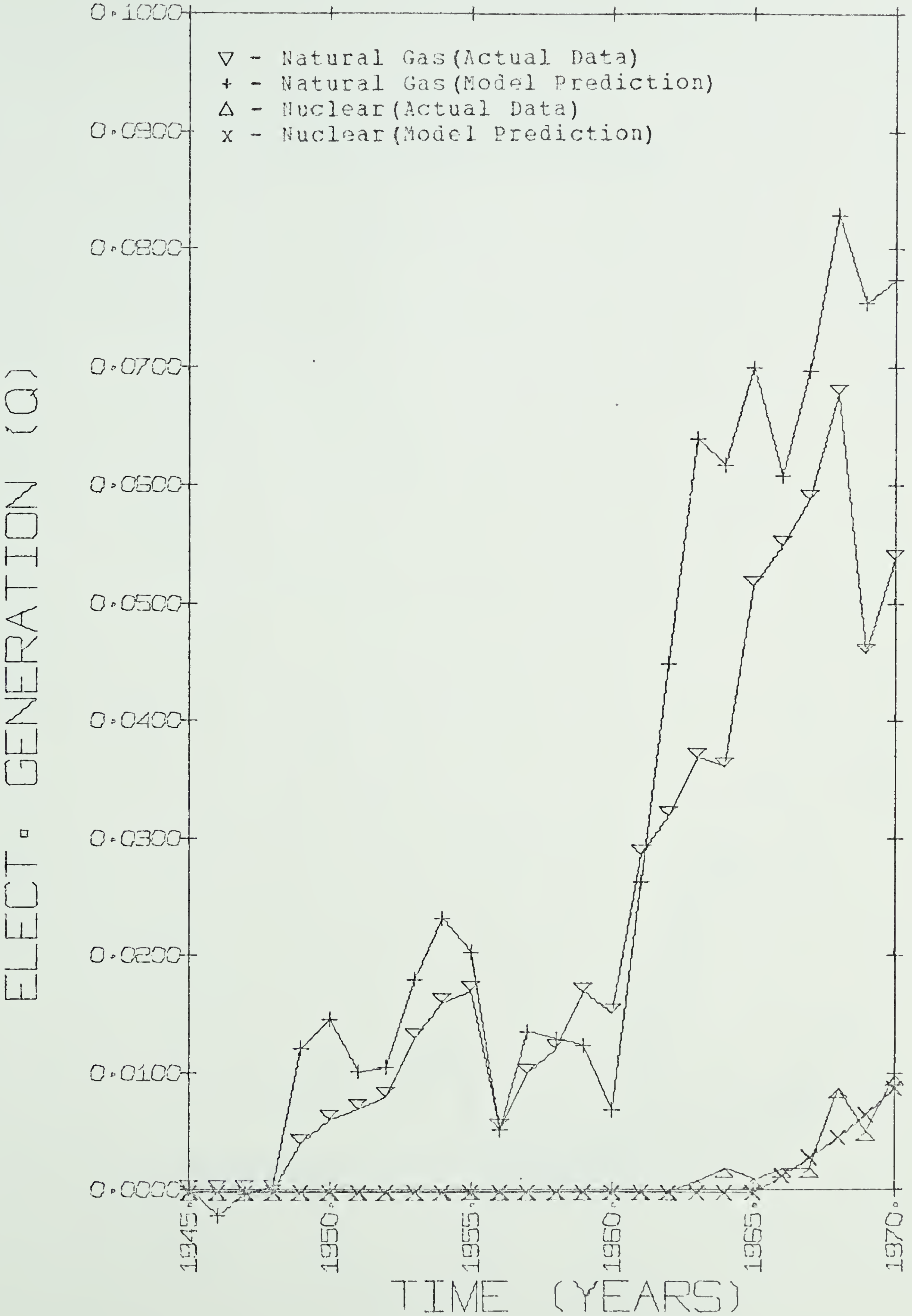

FIGURE III.14 - ELECTRICITY GENERATION FROM NUCLEAR AND NATURAL GAS, BASE CASE 1945-70.

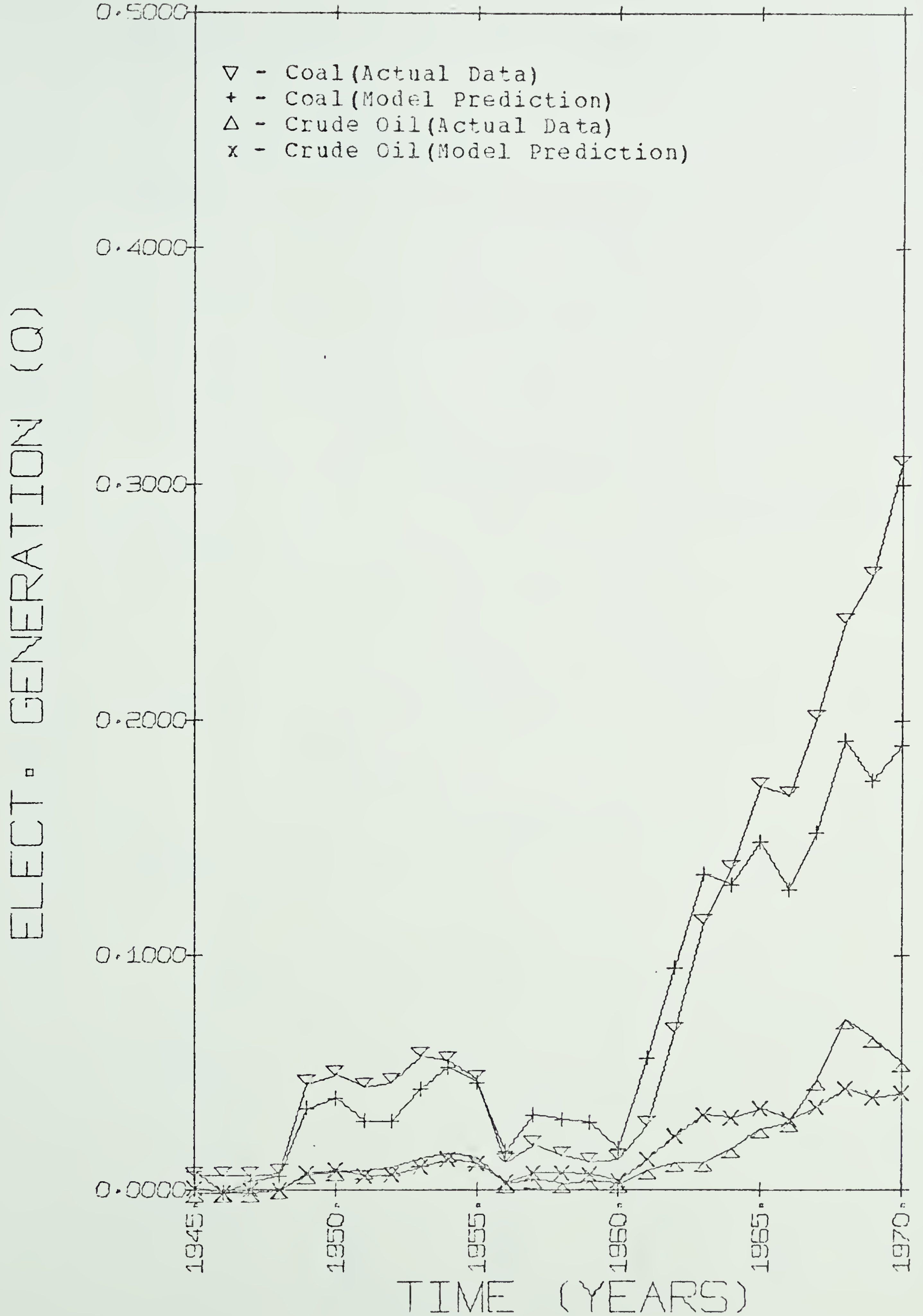

FIGURE III.15 - ELECTRICITY GENERATION FROM COAL AND CRUDE OIL, BASE CASE 1945-70.

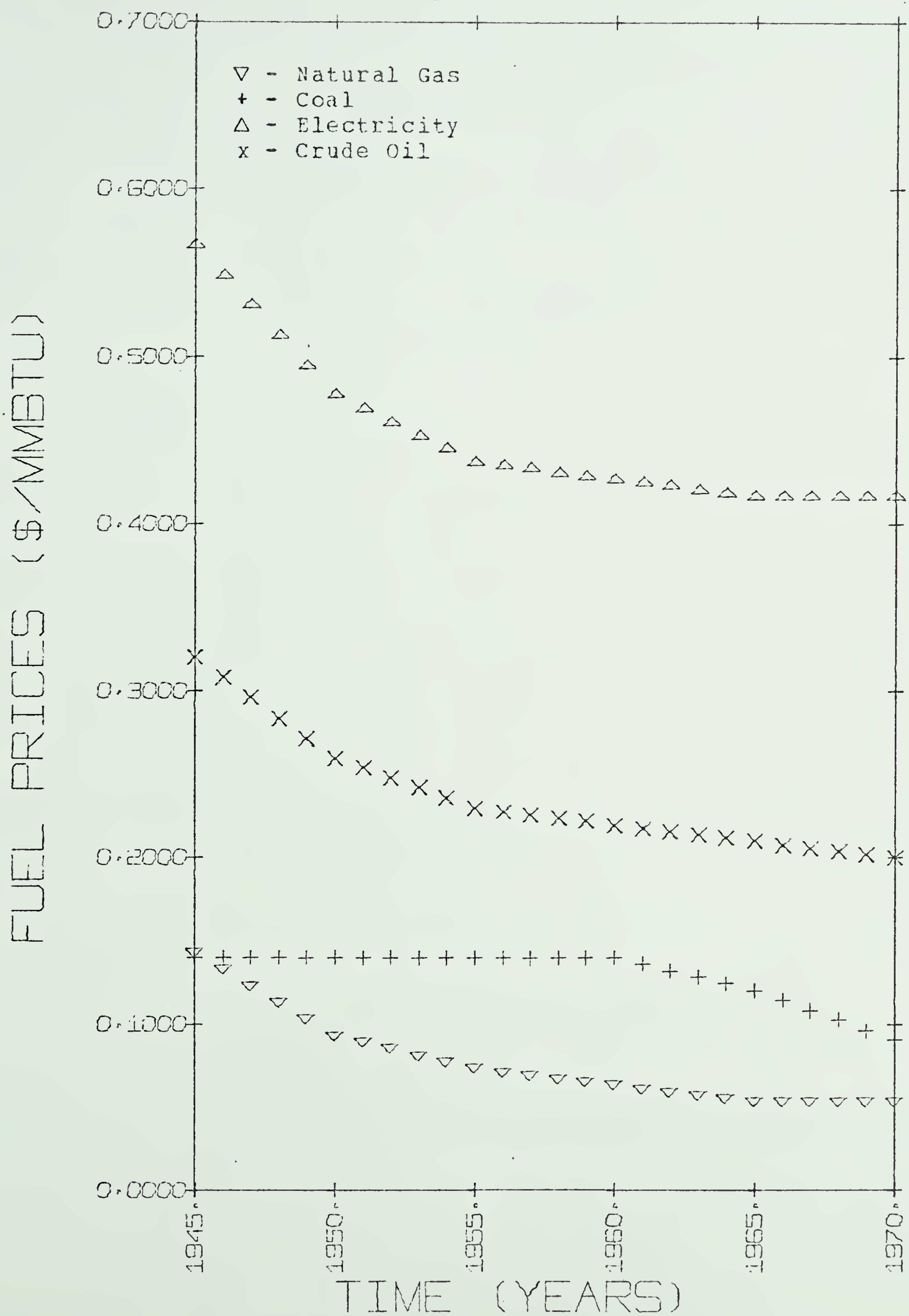

FIGURE III.16 - FUEL PRICES, BASE CASE 1945-70.

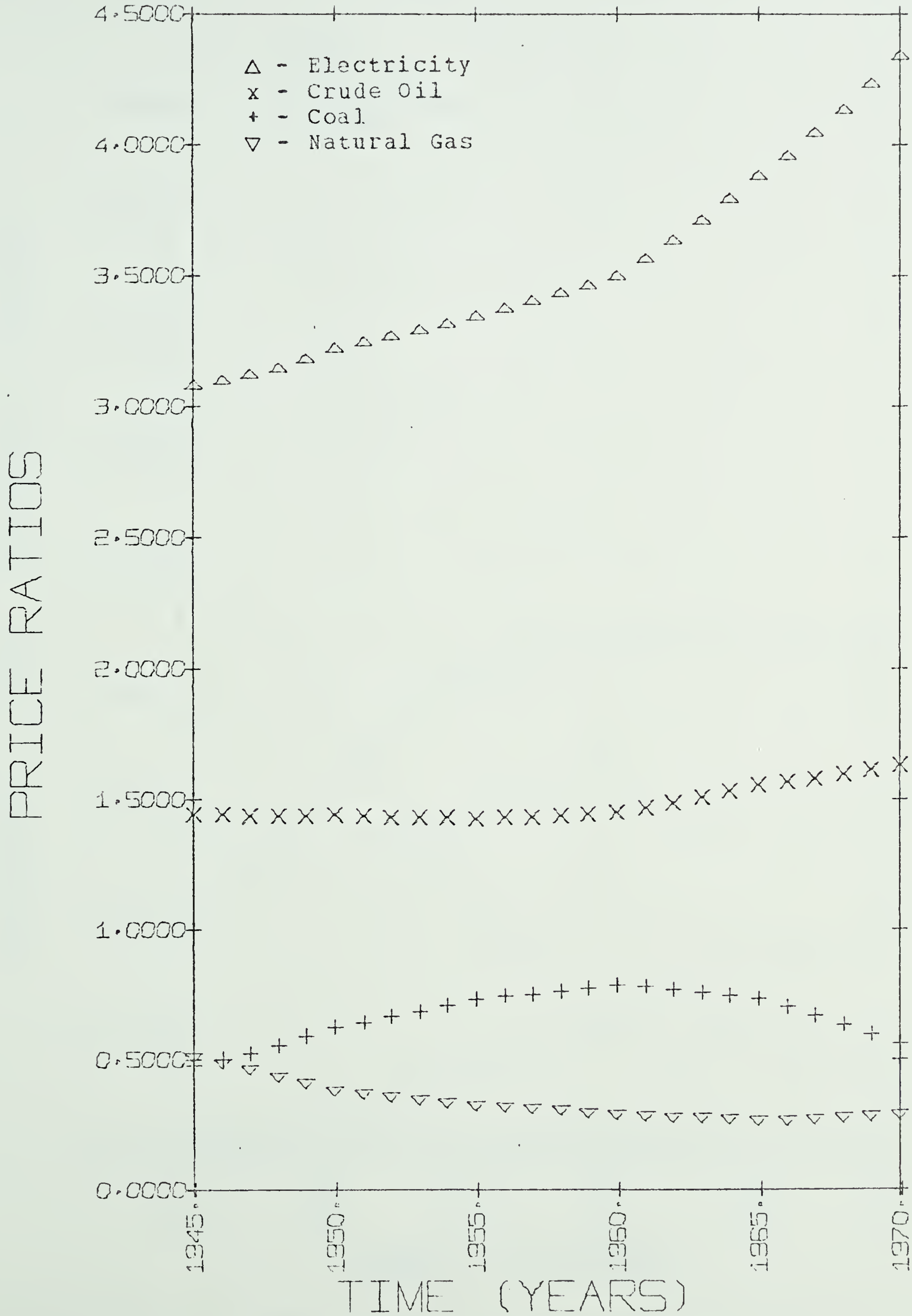

FIGURE III.17 - RELATIVE PRICES OF FUELS, BASE CASE 1945-70.

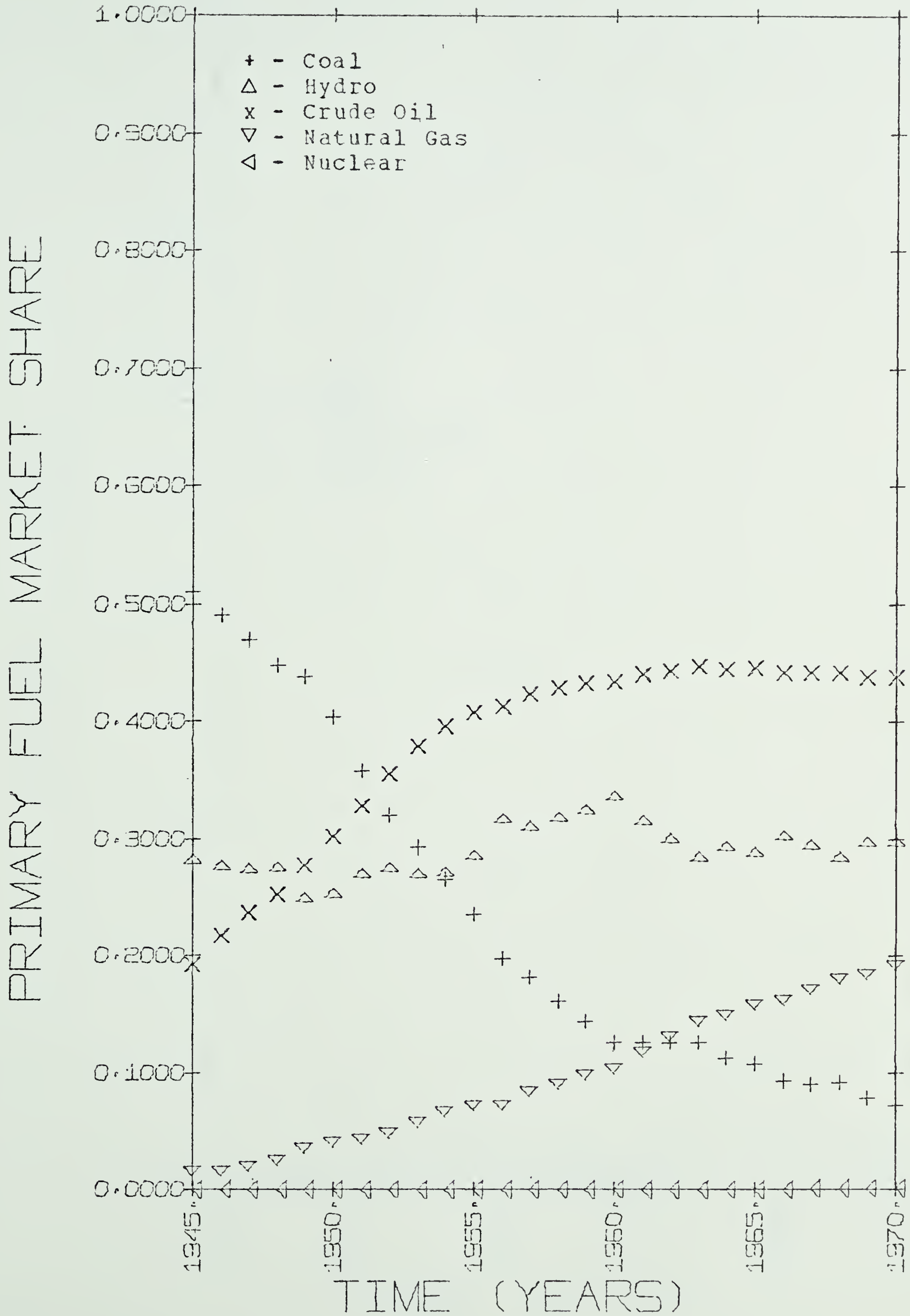

FIGURE III.18 - TOTAL MARKET SHARES OF PRIMARY FUELS, BASE CASE 1945-70.

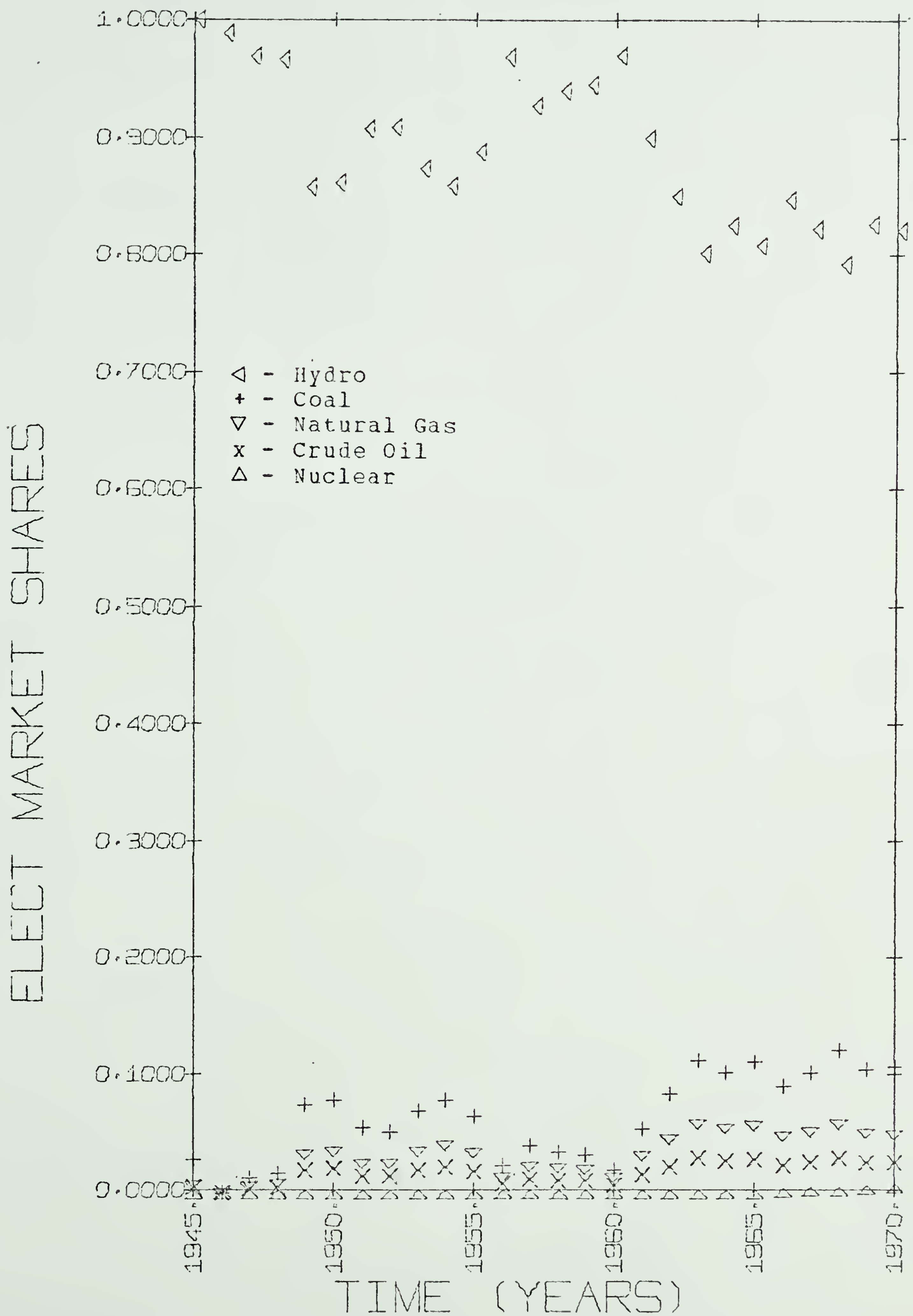

FIGURE III.19 - MARKET SHARES OF PRIMARY FUELS IN ELECTRICITY GENERATING SECTOR, BASE CASE 1945-70.

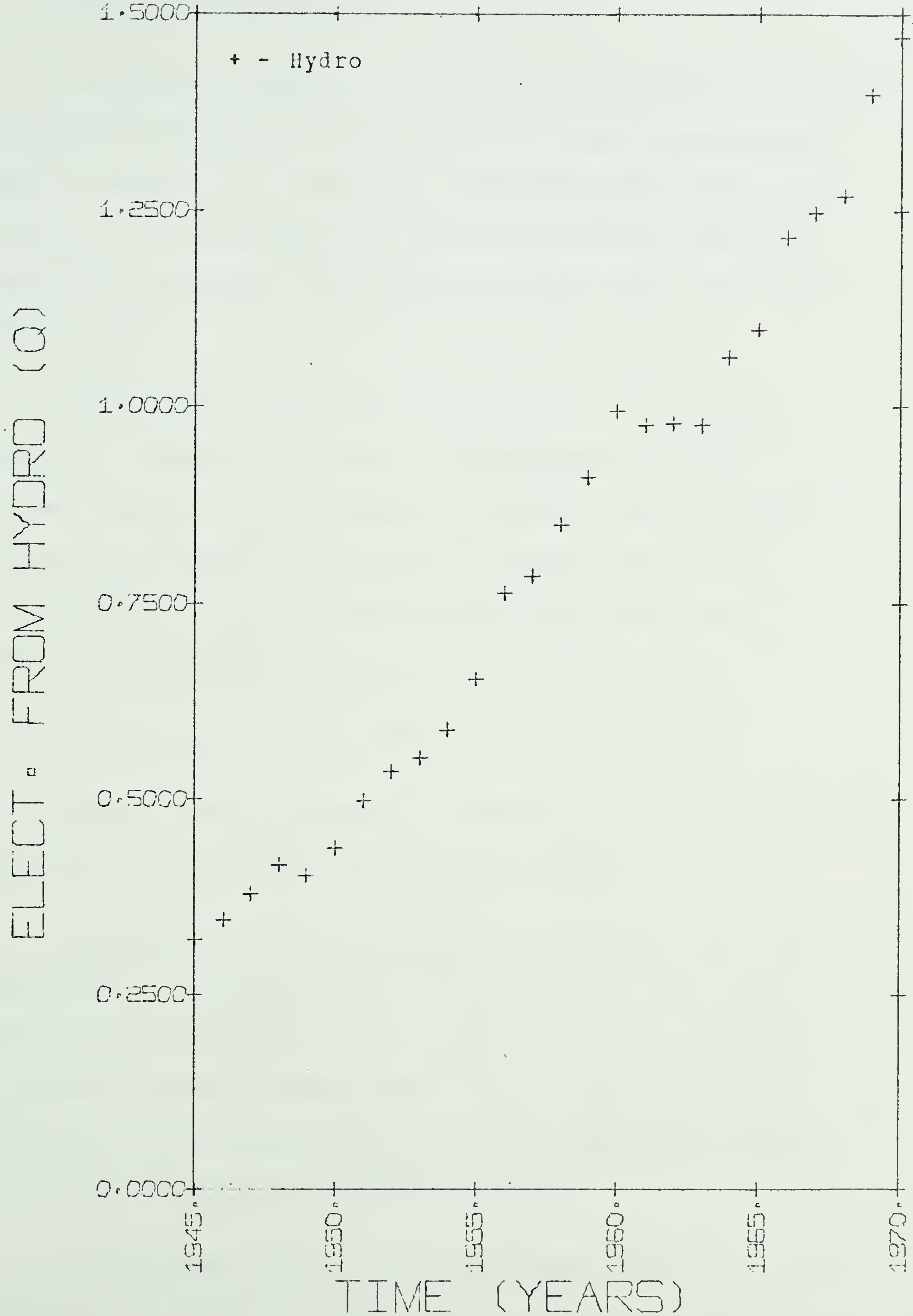

FIGURE III.20 - QUANTITY OF ELECTRICITY PRODUCED FROM HYDRO, BASE CASE 1945-70.

iv. Perturbation Tests

A useful exercise in validating mathematical models is to subject the model to large-scale shocks and to observe the results for anticipated or unexpected behavior. If the results of the perturbation tests are unexplainable and obviously incorrect, the validity of the model may then be questioned.

Perturbation tests were conducted on the Canadian Interfuel Substitution Model by introducing radical changes in fuel prices, fossil capacity fraction and the quantity of electricity produced from hydro. Although the results are not presented here, the model passed the perturbation tests since no unacceptable results were observed.

v. Realism of Model Parameters

Are the values assigned to parameters within the model realistic in their economic interpretation?

Certainly all those parameters associated with the distribution multipliers are realistic since they were statistically estimated from actual data. The estimation procedure included examination for the expected signs of the parameters where important in order to determine whether or not they correspond to economic theory.

As mentioned earlier, the commitment liberation rates correspond to assumed values which are already intuitively correct in their magnitude.

It is now believed that the model has successfully been demonstrated to be valid according to the definition of validity used here. To deny that inadequacies exist in the model would be unrealistic. The model must be understood with all of its strengths and weaknessess and any statements or conclusions must be made in the light of the capabilities of the model.

CHAPTER IV

ANALYSIS AND RESULTS

In order to exercise and assess the usefulness of the 'Canadian Interfuel Substitution Model', a detailed examination of the model will attempt to reveal some diverse aspects of the energy demand patterns in Canada. The first phase of the analysis will investigate the historical (1945-70) energy demand patterns in Canada. This will consist of establishing some general observations concerning the historical demand patterns before proceeding to an analysis of the price elasticities of these energy demands. In the second phase of the analysis some future projections will be made based on various price and commitment liberation rate scenarios. Finally, the policy implications of the earlier analysis will be outlined.

A. GENERAL OBSERVATIONS

The primary demand sector growth rates have been larger in Canada than the United States for the period 1945-70. There are two major factors contributing to Canada's larger growth rate in energy consumption:

1.) The Canadian average annual population growth rate has been significantly larger than that for the USA. It is generally accepted that the total energy consumption of a country is closely correlated with its population size.

2.) The level of Canadian energy consumption per capita has been lower than that in the USA and

> growing at a faster rate. Although a controversial theory, it has been hypothesized (32) that the energy consumption per capita in a growing economy follows an 'S' curve over time, eventually reaching a saturation level. Proponents of this theory point to the fact that the American energy consumption per capita is growing at a declining rate and they believe that it is nearing saturation.

Table IV.1 contains the comparative data of Canadian and American energy consumption patterns.

TABLE IV.1

Growth Rates of Energy Consumption for Canada and USA

(1945-70)

	Population Growth Rate (%/Year)	Primary Demand Sector Growth Rates (%/Year)			Annual Average Per Capita Energy Consumption (BTUx10^6)	Growth Rate of Annual Average Per Capita Energy Consumption (%/Year)
		RCD	IHD	TRD		
Canada	2.26	7.16	4.55	3.05	181.2	2.72
USA	1.74	3.74	2.47	2.70	217.7	1.31

Within the primary demand sectors of Canada there have existed, since 1945, relatively smooth and definite trends with regards to the preferences for particular energy forms[1].

Coal has made a transition from being the most demanded

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[1] refer to Figures IV.3 and IV.4, the time-varying fuel market shares.

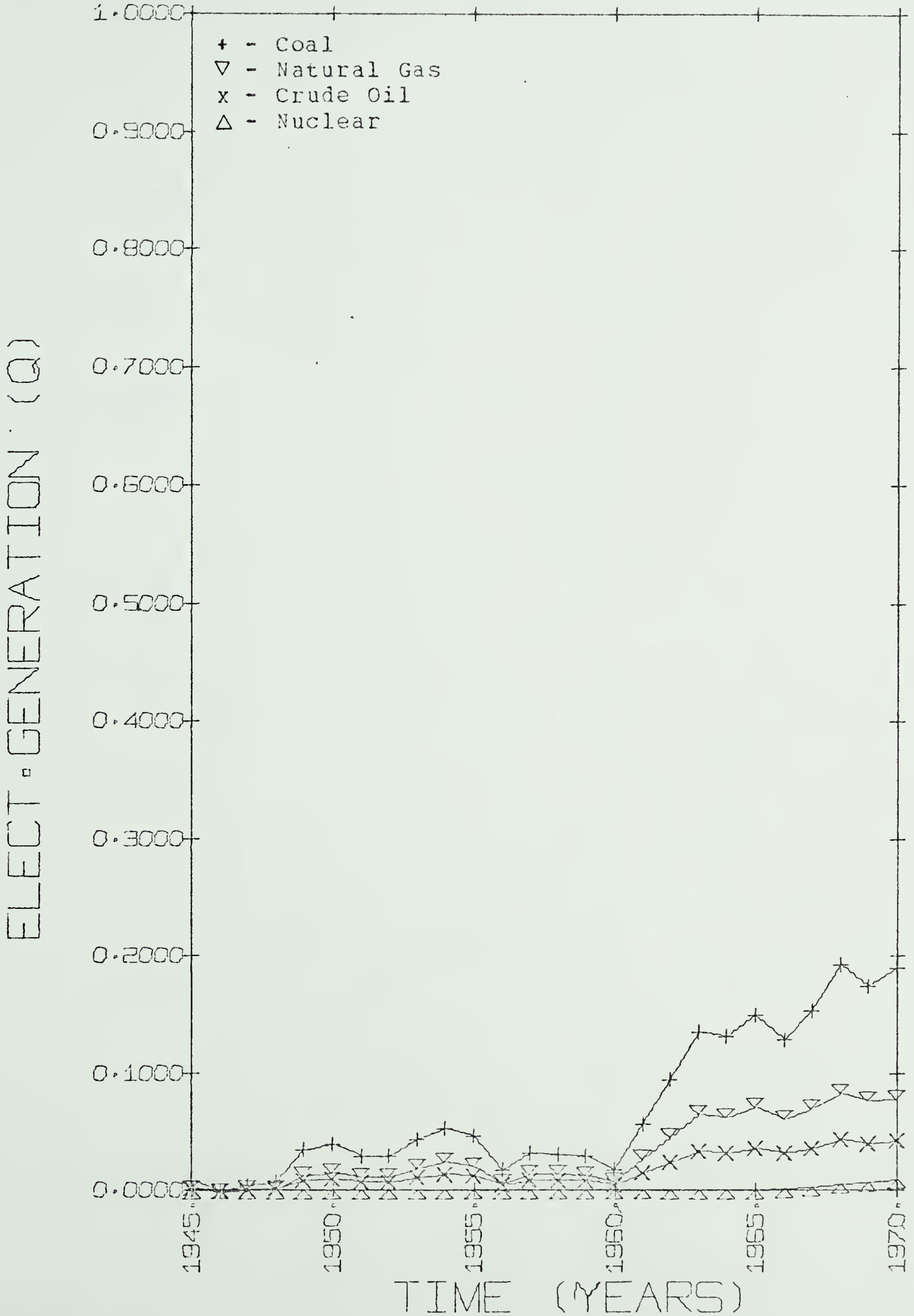

FIGURE IV.1 - ELECTRICITY GENERATION FROM PRIMARY FUELS, BASE CASE 1945-70.

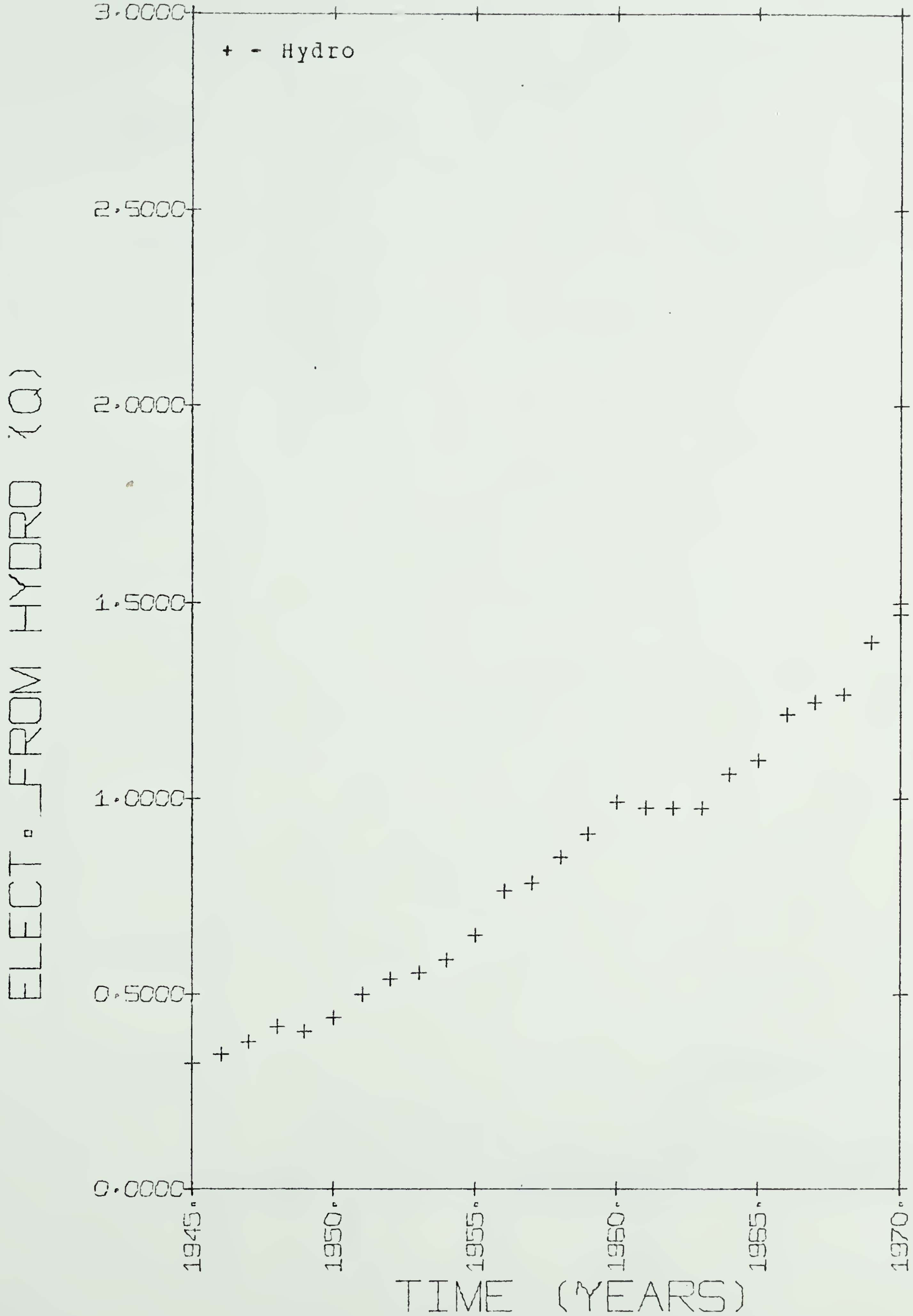

FIGURE IV.2 - ELECTRICITY GENERATED FROM HYDRO, BASE CASE 1945-70.

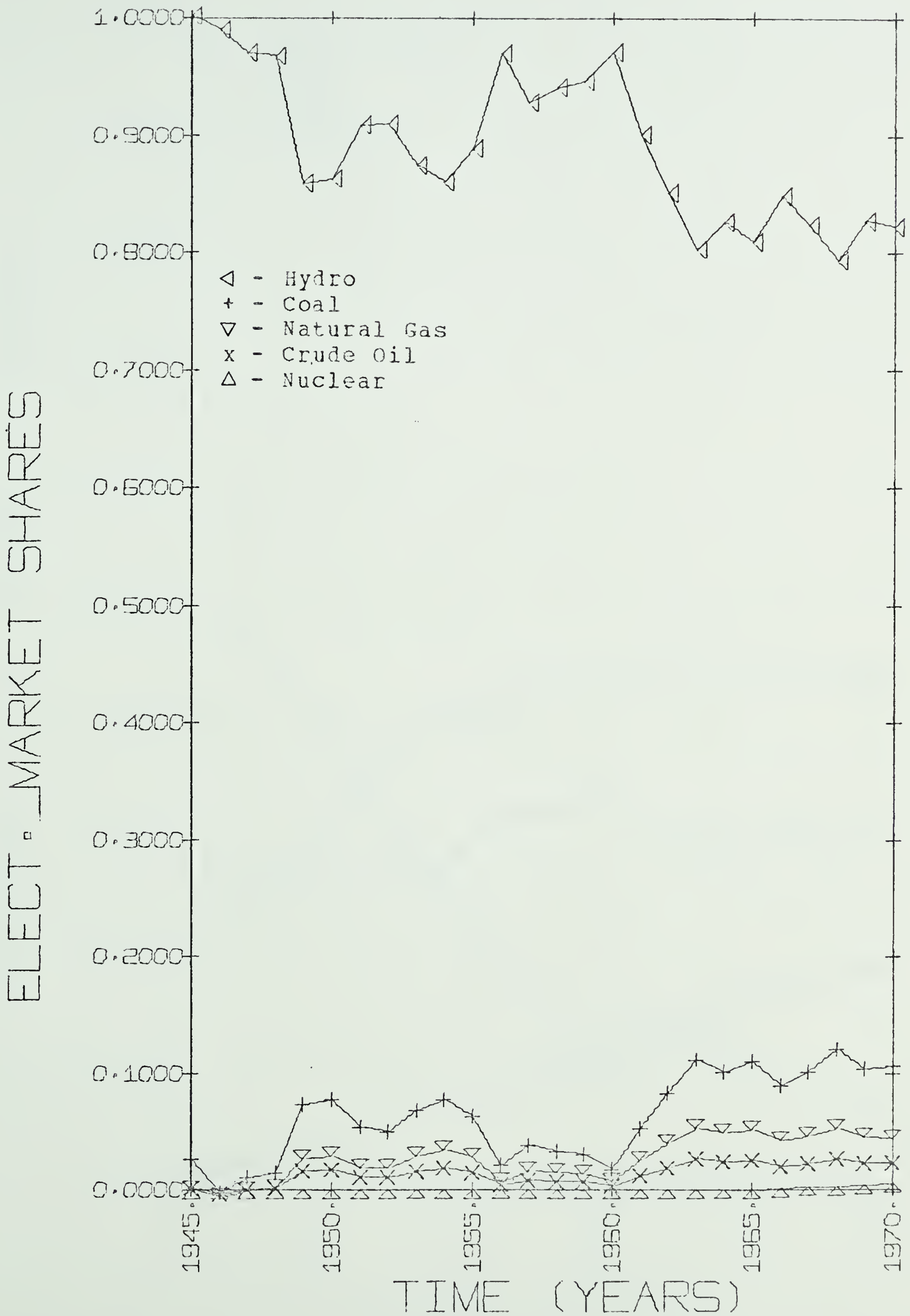

FIGURE IV.3 - PRIMARY FUEL MARKET SHARES IN ELECTRICITY GENERATING SECTOR, BASE CASE 1945-70.

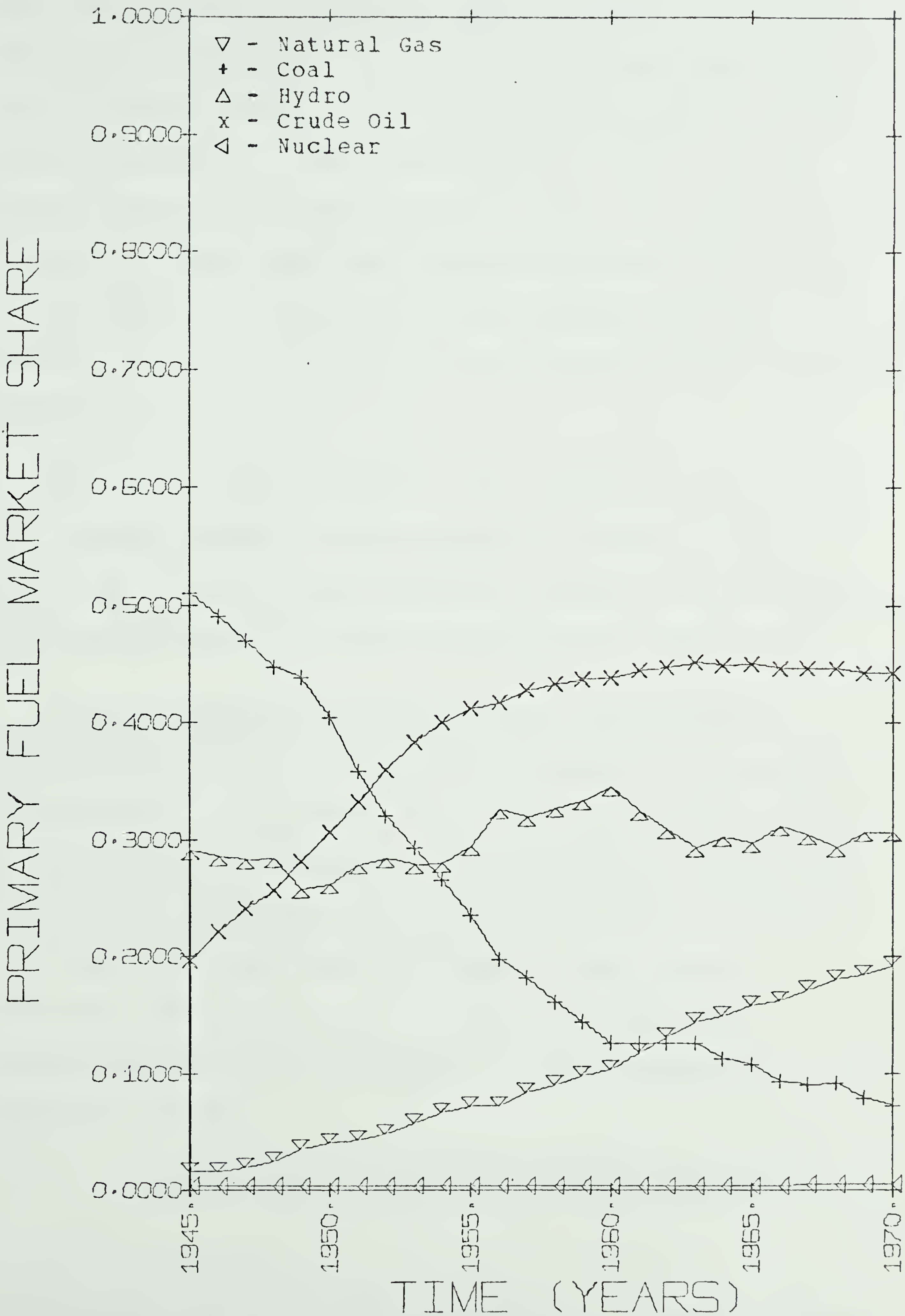

FIGURE IV.4 - PRIMARY FUEL MARKET SHARES OF TOTAL CANADIAN ENERGY CONSUMPTION, BASE CASE 1945-70.

fuel form in 1945 to being the least demanded fuel form in 1970. It is estimated[1] that in 1945 coal constituted 50% of all the primary energy forms[2] utilized in Canada. By 1970 the market share of coal had declined to less that 10%. Several factors have contributed to this transition: the prices of competitive fuels declined relative to the price of coal; serious transportation and handling problems existed with coal; and environmental concerns discriminated against coal as a 'dirty' fuel.

During the period 1945-55, the importance of crude oil as a primary source of energy grew very rapidly. However, since 1955 the more rapid growth in natural gas consumption has prevented crude oil from increasing its market share.

The electricity generating sector has exhibited sporadic behavior in the past with regards to its demands for particular fuel forms[3]. This sector is a public utility in most provinces of Canada. The monopolistic operation of the electric utilitites has enabled this sector to operate on a very large scale with adherence to long range objectives and planning. As a result, the following characteristics may be attributed to the electricity generating sector:

1.) Based on environmental, technical, and cost considerations, hydro and nuclear generated

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[1] refer to 'Base-Case' market shares.
[2] the primary fuels are coal, natural gas, crude oil, hydro, and nuclear (W,X,Y,H, and N respectively).
[3] see Figures IV.1 to IV.3, electricity market shares.

electricity can be justified only when operating at full or near-full capacity. Therefore, large-scale hydro and nuclear projects are brought to full capacity shortly after completion to satisfy incremental demand and replace, at least temporarily, electricity produced by the less efficient fossil plants.

2.) Because of the attention given to long range objectives, the fossil consuming component of this sector is designed for a great deal of flexibility. The fossil generating plants of most provincial power systems are able to react on a month-to-month basis to changing market conditions of fossil fuels.

The above characteristics explain a large measure of the fluctuating behavior of the electricity generating sector. In spite of its sporadic and seemingly random behavior, the electricity generating sector is gradually reducing its hydro market share[1]. This is necessary in view of the fact that demand for electricity is steadily growing while the potential for hydro power is nearing its upper limit. Although the lost market share of hydro power has been captured by fossil power in the last decade, it is expected that nuclear power will become a major source of electrical energy in the near future.

The preceding discussion recognizes that several factors contribute to the determination of a consumer's fuel preferences. These factors include fuel prices, conversion equipment costs, availability, technological constraints and convenience of use. Unfortunately, the quantification of the roles and relative impacts that all these factors have in

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[1] see Figure IV.3, electricity market shares.

the total decision-making process is extremely difficult. In fact, a meaningful discussion of the non-price factors would require a regional analysis of consumer behavior.

B. DEMAND ELASTICITIES

There are primarily two characteristics of an energy demand sector which determine the magnitude of that sector's demand elasticity for any given fuel. These two characteristics are:

1.) the ratio of free (market sensitive) demand which is satisfied by fuel n to the total demand for that fuel.

2.) the elasticity of the free demand which is satisfied by fuel n with respect to the relative price for that fuel.

In the event that the ratio of free demand which is satisfied by fuel n to the total demand for this fuel is very small for any given sector, it is virtually guaranteed that the price elasticity of total demand for this fuel will also be small. This is true since the base demand for any fuel is by definition perfectly inelastic. However, if the ratio of free demand to total demand for a fuel is large, then the price elasticity of the total demand for the given fuel in this sector is dependent on the elasticity of the free demand which is satisfied by the particular fuel in question.

Therefore, in analyzing the price elasticity of demand for each fuel in each sector, the following data will be

presented for each consumer category for the period 1945-70:

- ratio of free demand which is satisfied by fuel _n_ to total demand for that fuel.

- price elasticity of free demand which is satisfied by each fuel form.

- price elasticity of total demand for each fuel form.

Before presenting the results, the derivation of the elasticity functions will be discussed. The market sensitive demand which is satisfied by any one fuel is represented in the model by the following function:

$$\underline{m}MSD\underline{n}(t) = \underline{m}DD\underline{n}(t) \times \underline{m}MSD(t) \qquad \text{(IV.1)}$$

for _m_ = RCD, IHD, and TRD.
_n_ = W, X, Y, and Z.
if _m_ = ZF (electricity generating sector)
then Equation IV.1 is true for _n_ = W, X, and Y.

where $\underline{m}MSD\underline{n}(t)$ = the quantity of free demand which is satisfied by fuel _n_ in sector _m_ at time t.
$\underline{m}DD\underline{n}(t)$ = the distribution multiplier for fuel _n_ in sector _m_ at time t.
$\underline{m}MSD(t)$ = the total free demand in sector _m_ at time t.

From equation IV.1 it is possible to derive a general expression for the elasticity of the free demand which is satisfied by any given fuel.

As a result of the manner in which the price variables enter into the model, the price elasticities may be considered with respect to two different price functions --- elasticity with respect to absolute price and elasticity with respect to relative price (price ratio). Preliminary studies of the elasticities with respect to absolute prices discouraged further work with this approach since the

elasticity functions were very complex and difficult to manipulate. In contrast to this approach, the elasticities with respect to the relative fuel prices are rather simple and manageable functions. Therefore, elasticity as it will be used here, will now be defined as the sensitivity of consumer demand for a particular fuel to changes in the relative price of that fuel.

The elasticity of free demand which is satisfied by fuel $\underline{n}$ is thus given by:

$$E[\underline{m}MSD\underline{n}(t)] = \frac{d[\underline{m}MSD\underline{n}(t)]}{d[P\underline{n}RATIO(t)]} \times \frac{P\underline{n}RATIO(t)}{\underline{m}MSD\underline{n}(t)}$$

$$= \frac{d[\underline{m}DD\underline{n}(t) \times \underline{m}MSD(t)]}{d[P\underline{n}RATIO(t)]} \times \frac{P\underline{n}RATIO(t)}{\underline{m}MSD\underline{n}(t)} \qquad (IV.2)$$

where $E[\underline{m}MSD\underline{n}(t)]$ = the elasticity of the free demand in sector $\underline{m}$ which is satisfied by fuel $\underline{n}$ ($\underline{m}MSD\underline{n}(t)$) with respect to the relative price of fuel $\underline{n}$ ($P\underline{n}RATIO(t)$) at time t.

Since the total market sensitive demand is not dependent on fuel price in the model, equation IV.2 reduces to:

$$E[\underline{m}MSD\underline{n}(t)] = \frac{\underline{m}MSD(t) \times d[\underline{m}DD\underline{n}(t)]}{d[P\underline{n}RATIO(t)]} \times \frac{P\underline{n}RATIO(t)}{\underline{m}MSD\underline{n}(t)} \qquad (IV.3)$$

One example of the general structure of these elasticity functions may be obtained by solving the derivative of the distribution multiplier with respect to the relative fuel price. This has been done for the industrial distribution multiplier for electricity. The

resulting elasticity function is:

$$E[IHMSDZ(t)] = \frac{-0.0112 \times [ITOTAL(t) - IHDDZ1(t)] \times IHMSD(t)}{ITOTAL(t)^2}$$

$$\times \frac{PZRATIO(t)}{[IHDDZ(t) \times IHMSD(t)]} \qquad (IV.4)$$

where IHMSDZ(t) = the quantity of free demand in the industrial sector which is satisfied by electricity at time t.
ITOTAL(t) = the sum of the initial estimates of all the distribution multipliers for the industrial sector.
IHDDZ1(t) = the initial estimate of the industrial distribution multiplier for electricity.
IHDDZ(t) = the normalized distribution multiplier for electricity in the industrial sector.
IHMSD(t) = the total free demand in the industrial sector at time t.
-0.0112 = the coefficient of the relative price of electricity in the initial equation for the electricity distribution multiplier.

Slight variations of this structure exist for other elasticities depending on the particular form of the distribution multiplier involved.

Two basic characteristics of the elasticities of the distribution multipliers are clear from the equation:

1.) the constant term in the elasticity function is fundamental in determining the relative range of elasticities that can occur. This constant is the correlation coefficient of the fuel price ratio in the initial equation for the distribution multiplier[1].
A detailed quantitative analysis of the elasticities must take into account the stochastic nature of this constant term.

2.) the elasticity of the distribution multiplier

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[1] see Appendix B for the estimation results.

> increases in absolute value as the fuel market share of free demand for that sector declines. This result is justified on the basis that as one particular fuel captures increasingly larger proportions of the market, there is a real decline in the number and extent of 'effective' competitor fuels. However, this feature of the elasticities can only be considered from the standpoint of short-run responses.

It is known by definition that the base demand for any given fuel is perfectly inelastic. Therefore, we may easily obtain the elasticity of total demand for fuel *n* in sector *m* by modifying the elasticity of free demand satisfied by fuel *n* in sector *m*. This is done by multiplying the elasticity of free demand by the ratio of free demand satisfied by fuel *n* to the total demand for fuel *n*.

$$E[\underline{m}d\underline{n}(t)] = \frac{d[\underline{m}MSD\underline{n}(t)]}{d[P\underline{n}RATIO(t)]} \times \frac{P\underline{n}RATIO(t)}{\underline{m}MSD\underline{n}(t)} \times \frac{\underline{m}MSD\underline{n}(t)}{\underline{m}d\underline{n}(t)} \qquad (IV.5)$$

$$= \frac{\underline{m}MSD(t) \times d[\underline{m}DD\underline{n}(t)]}{d[P\underline{n}RATIO(t)]} \times \frac{P\underline{n}RATIO(t)}{\underline{m}d\underline{n}(t)} \qquad (IV.6)$$

Thus, the two elasticity functions in which we are interested in are represented mathematically by equations IV.3 and IV.6. Equation IV.3 determines the elasticity of the free demand which is satisfied by fuel *n* in sector *m*. Equation IV.6 determines the elasticity of the total demand for fuel *n* in sector *m*.

These elasticity functions will now be discussed in regards to the demand sectors of the Canadian Interfuel Substitution Model.

RESIDENTIAL AND COMMERCIAL SECTOR[1]

Coal demand in this sector has been, since 1945, much more sensitive to price changes than the demand for any other fuel. This fact, coupled with the declining residential-commercial coal market share, results in the elasticity of free demand which is satisfied by coal being the largest of all the demand elasticities in this sector. The elasticity of the free demand which is satisfied by coal continues to increase as the coal market share of free demand declines.

As the coal consumers in the residential-commercial sector begin to substitute other fuels for coal there is a marked decline in the ratio of free demand which is satisfied by coal to the total demand for coal. This trend influences the elasticity of total demand for coal by greatly reducing it as compared to the elasticity of free demand for coal. Despite this fact, the trends of the elasticities of total and free demand for coal are remarkably similar.

Crude oil demand in the residential-commercial sector has been completely insensitive to price changes since 1945. Thus, the price elasticity of the free demand which is satisfied by crude oil has been zero. Although the ratio of free demand to total demand for crude oil has been quite dynamic since 1945, the elasticity of the total demand for

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[1] see Figures IV.5 to IV.8.

this fuel is nonetheless zero.

The elasticity of the free demand committed to electricity has been steadily declining since 1945 as the proportion of free demand satisfied by electricity increases. The elasticity of total demand for electricity in this sector has generally been low (<.05) since the ratio of free demand to total demand for this fuel has been small.

The behavior of the elasticities of the demand for natural gas have been very similar to that of electricity.

INDUSTRIAL SECTOR[1]

In the past, the coal distribution multiplier for the industrial sector has been independent of price and hence the demand elasticities have been zero.

All other fuels in this sector have had relatively inelastic fuel demands and, with the exception of natural gas, these elasticities have been quite stable since 1945.

The comparatively large elasticity of total demand for natural gas is explained in part by the large ratio of free demand to total demand that these consumers possessed. This is particularly true for the period 1945-55.

It may be of interest to note at this time the relationship between the ratio of free demand to total demand for fuel _n_ and the length of time in which this fuel

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[1] see Figures IV.9 to IV.11.

has been consumed in the given sector. Any fuel which is being consumed for the first time by a sector will naturally result in a very large ratio of free demand to total demand. The magnitude of the demand ratio will depend on the rate at which the given sector adopts this fuel. It is possible for the ratio of free demand to total demand to approach 1.0 if the 'new' fuel is introduced at a rapid rate. However, as the consumption period of a fuel is extended the ratio of free to total demand will eventually settle within a range which is generally much smaller than 1.0 (i.e. $\leq .25$).

TRANSPORTATION SECTOR[1]

As expected, the free demand for coal in the transportation sector has been very elastic and tends to increase in absolute value in the sixties as the coal market share of free demand declines. A very similar trend exists for the elasticity of total demand for coal although the magnitude of elasticity is reduced somewhat due to the declining ratio of free demand to total demand.

Compared to coal, the free demand for crude oil and thus, the total demand for crude oil have been very inelastic in this sector.

ELECTRICITY GENERATING SECTOR[2]

The interfuel substitution behavior of the electricity generating sector is quite different from any other sector.

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[1] see Figures IV.12 to IV.16.

[2] see Tables IV.2 to IV.4.

This difference in behavior is explained primarily by the economics of hydro generation. Hydro generating projects typically have large capital costs and low operating costs associated with them. Once the construction of a hydro project is completed, the economics of the project dictate that the plant be brought on-line at its maximum capacity as soon as possible. This may even result in reducing the output from fossil plants to below their capacity. It is a fact that the introduction of hydro plants in varying sizes and at seemingly random time periods has resulted in a fluctuating demand for fossil generated electrical power. In turn, this sector's demands for crude oil, natural gas, and coal have had corresponding fluctuations.

In analyzing the elasticities of demand for fossil fuels in this sector, one common problem must be clarified. The rapid substitution of hydro power for fossil power may result in all of the replacement demand of fossil plants being captured by the hydro plants. In addition to this loss of fossil generating capacity, the hydro generated power may also capture some of the base demand supplied by fossil plants. This will force a reduction in the utilization rate of the fossil capacity. In terms of the model this simply means that it is possible for the proportion of free demand which is committed to fossil generation to be negative under such conditions. There can be no meaningful economic interpretation of elasticity of free demand if this quantity is negative. Although the utilization rate of the base

fossil production is reduced, this reduction is independent of any fuel price changes. We must consider the elasticity of the total demand for fossil fuels under these conditions to be zero.

It is clear from the data that the price elasticity of free demand for gas has been invariably larger than the corresponding elasticities for coal and crude oil in the electricity generating sector. The price elasticity of free demand for natural gas has tended to slowly decline as the relative price of natural gas declines. Although the price elasticity of free demand for crude oil in this sector has been very small, it has remained virtually unchanged since 1950. For each fuel, the price elasticities of total demand have approached the elasticities of free demand as the ratios of free demand to total demand have approached 1.0.

In concluding the analysis of the demand elasticities, some final comments concerning the results are required.

Any extrapolations into the future of the elasticities and their trends must take into account that these elasticities apply to a period of time when energy costs were stable and relatively low compared to other commodities. Those demands that have been perfectly inelastic in the past would inevitably become elastic if the corresponding fuel prices were to increase relative to other commodity prices. However, the short-run response of inelastic consumers to rapid and dramatic price increases

would probably involve adjustments in their level of energy consumption rather than an immediate interfuel substitution. A similar response would be displayed by consumers in the event of a physical disruption of supplies of one or more particular fuel forms.

The commitment liberation rates in the model have been assumed to be independent of fuel price when in fact a degree of dependence may exist. Consequently, it is believed that the model may be producing under-estimates of the sector free demands. This is particularly true in times of rapid price changes. These biased estimates will be passed on and they will yield low estimates of the sector demand elasticities.

In several cases the relative fuel prices are not the only determinants of the distribution multipliers. What then, are the implications of the non-price factors in regards to the elasticities of the fuel demands? Initially it must be recognized that the purpose of elasticity studies is to determine to which influences a variable is sensitive and to quantify the magnitude of this sensitivity. Therefore, the elasticity studies of the sector demands are not complete until the variables representing TIME in each equation are disaggregated into their basic components, and the corresponding elasticities estimated. Although this final step has not been taken here, the importance of the TIME variables (and probably the related elasticities) should not be overlooked.

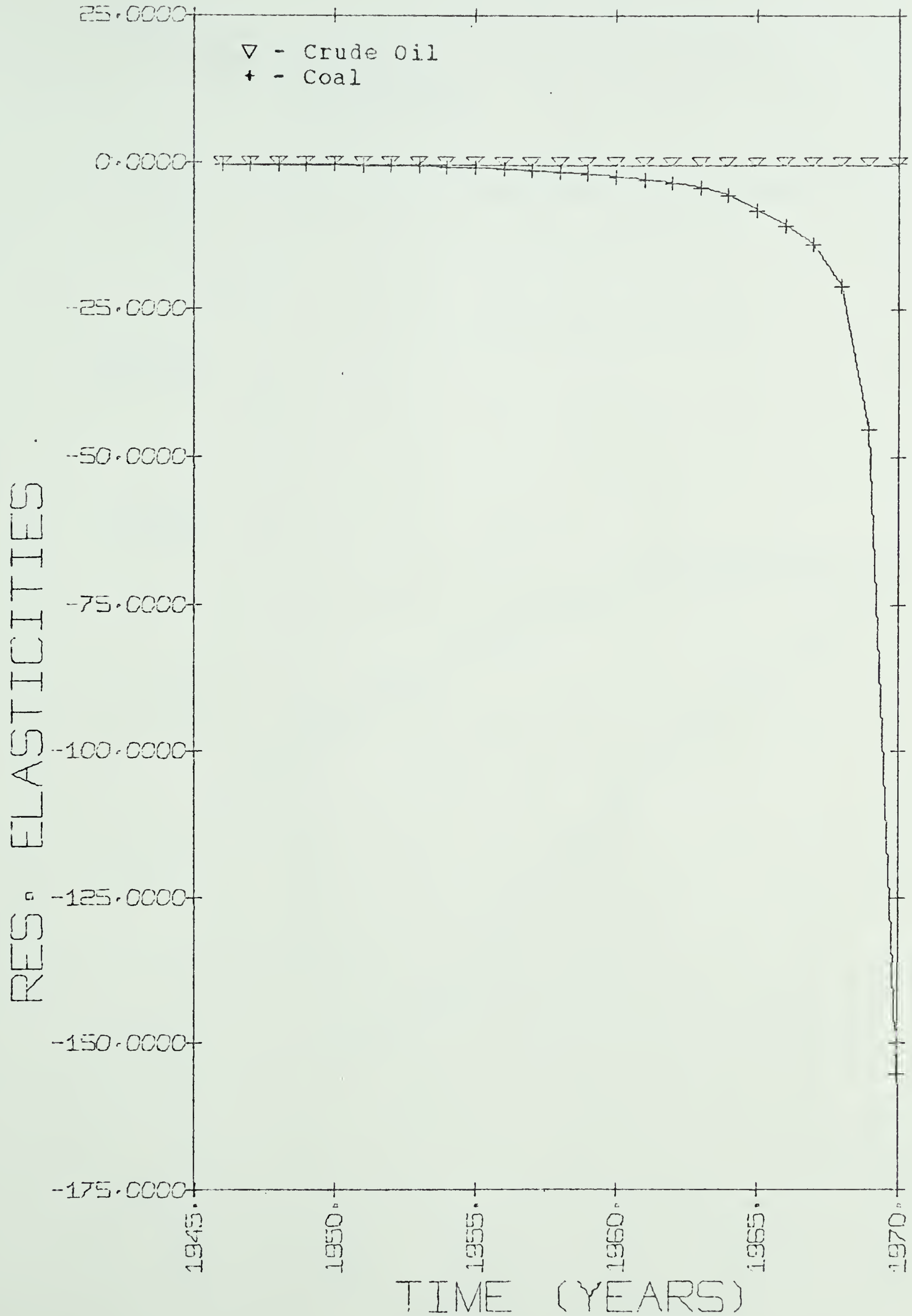

FIGURE IV.5 - ELASTICITY OF FREE DEMAND FOR RESIDENTIAL-COMMERCIAL SECTOR, BASE CASE 1945-70.

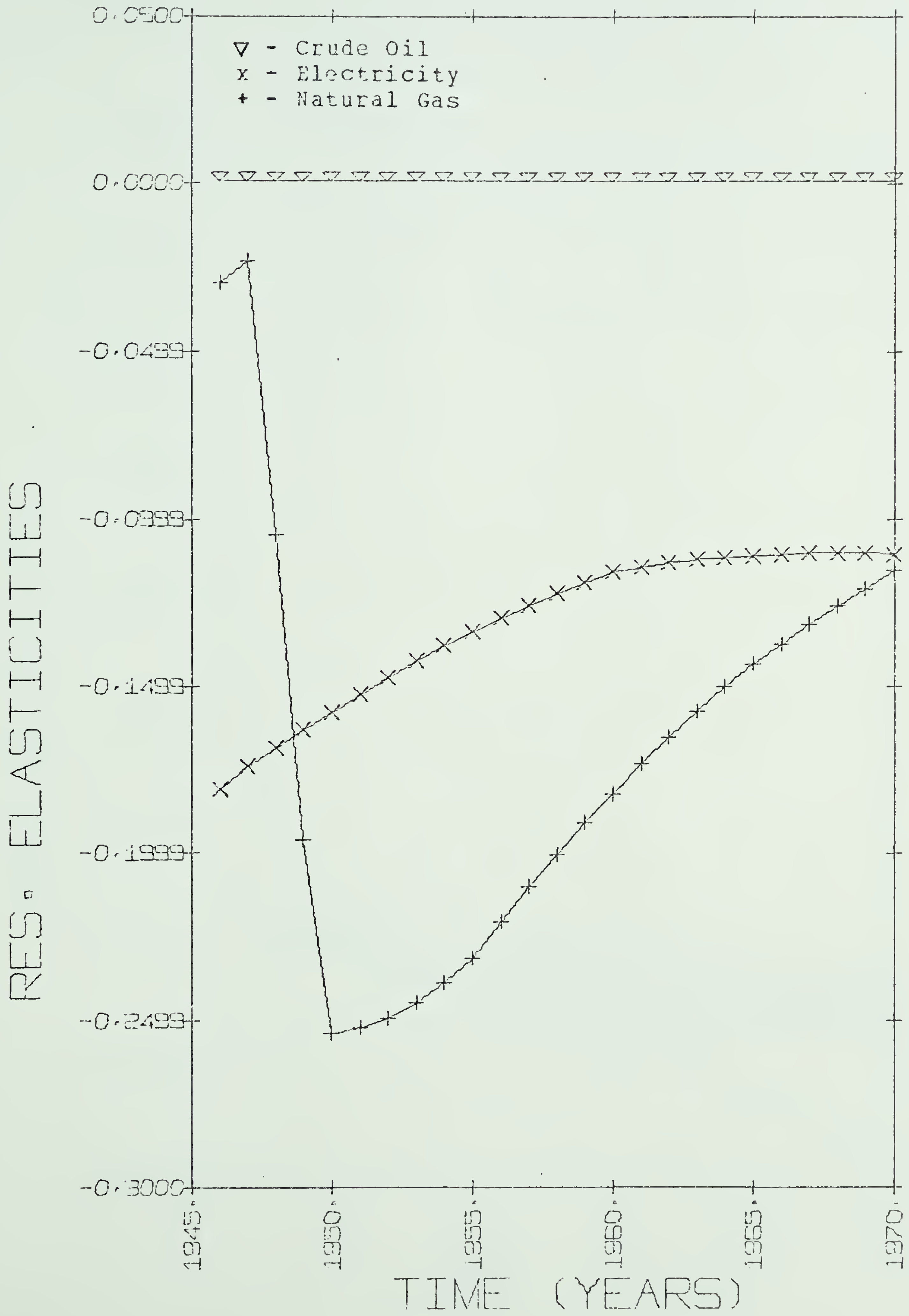

FIGURE IV.6 - ELASTICITY OF FREE DEMAND FOR RESIDENTIAL-COMMERCIAL SECTOR, BASE CASE 1945-70.

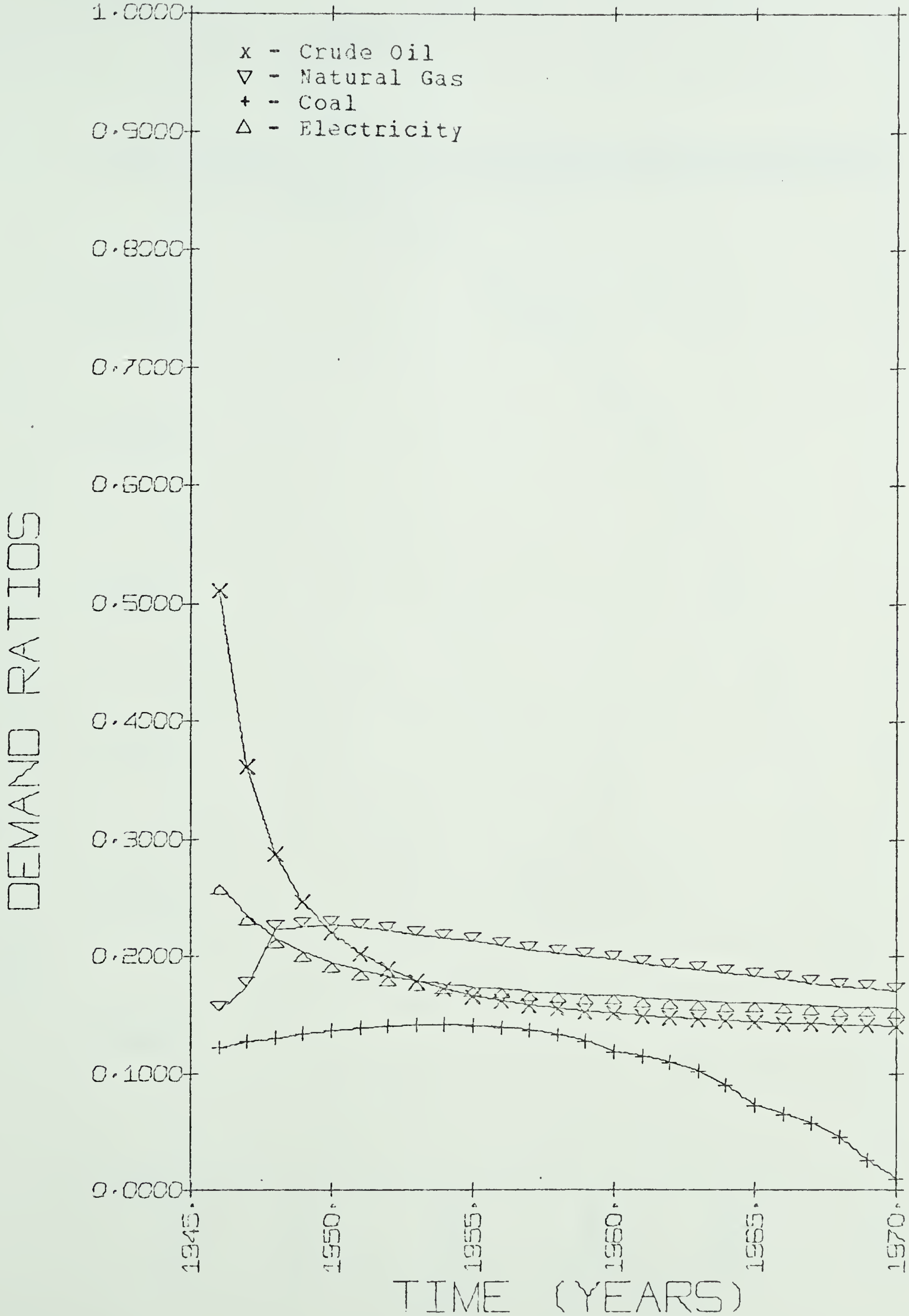

FIGURE IV.7 - RATIO OF FREE DEMAND TO TOTAL DEMAND FOR RESIDENTIAL-COMMERCIAL SECTOR, BASE CASE 1945-70.

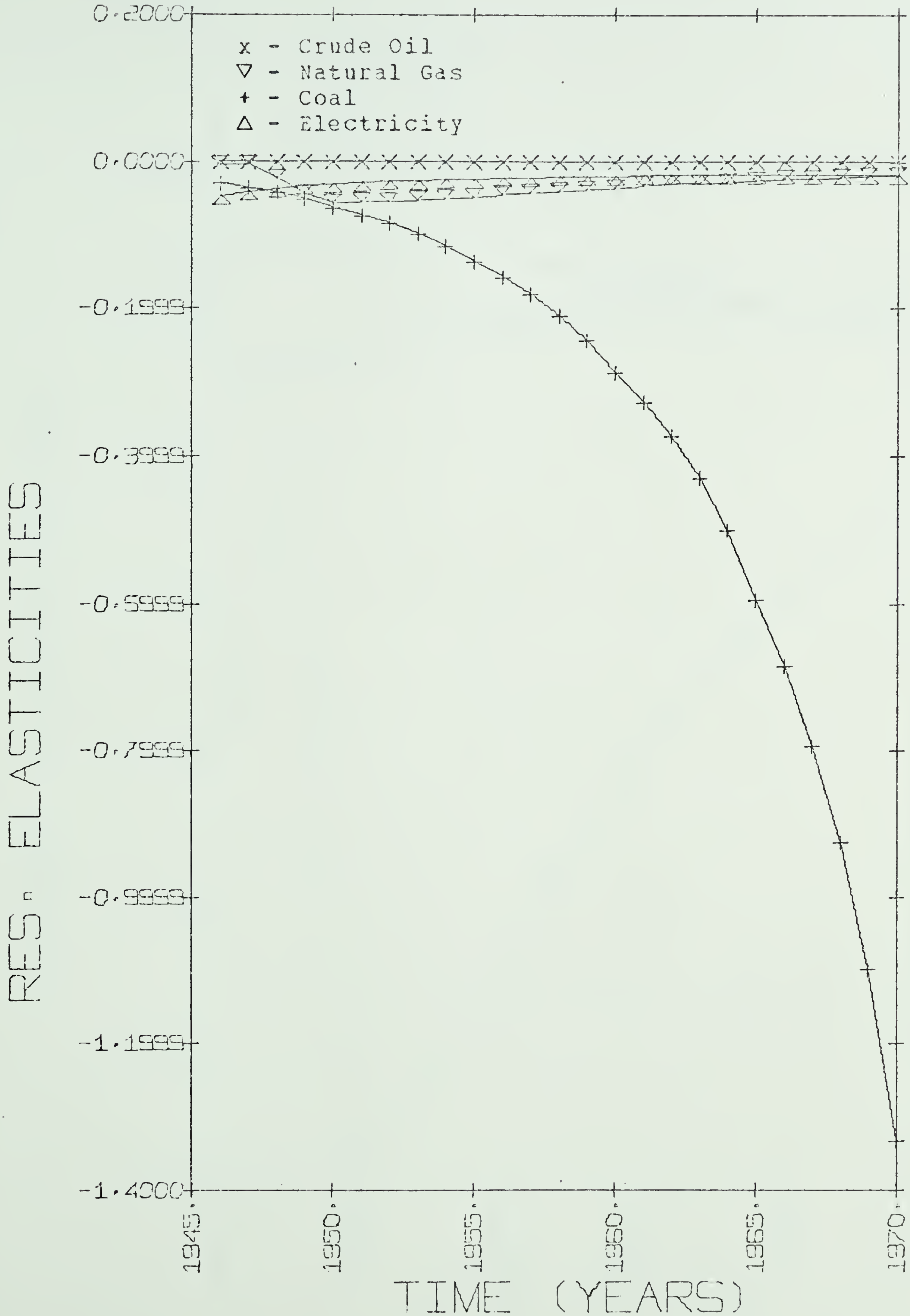

FIGURE IV.8 - ELASTICITY OF TOTAL DEMAND FOR RESIDENTIAL-COMMERCIAL SECTOR, BASE CASE 1945-70.

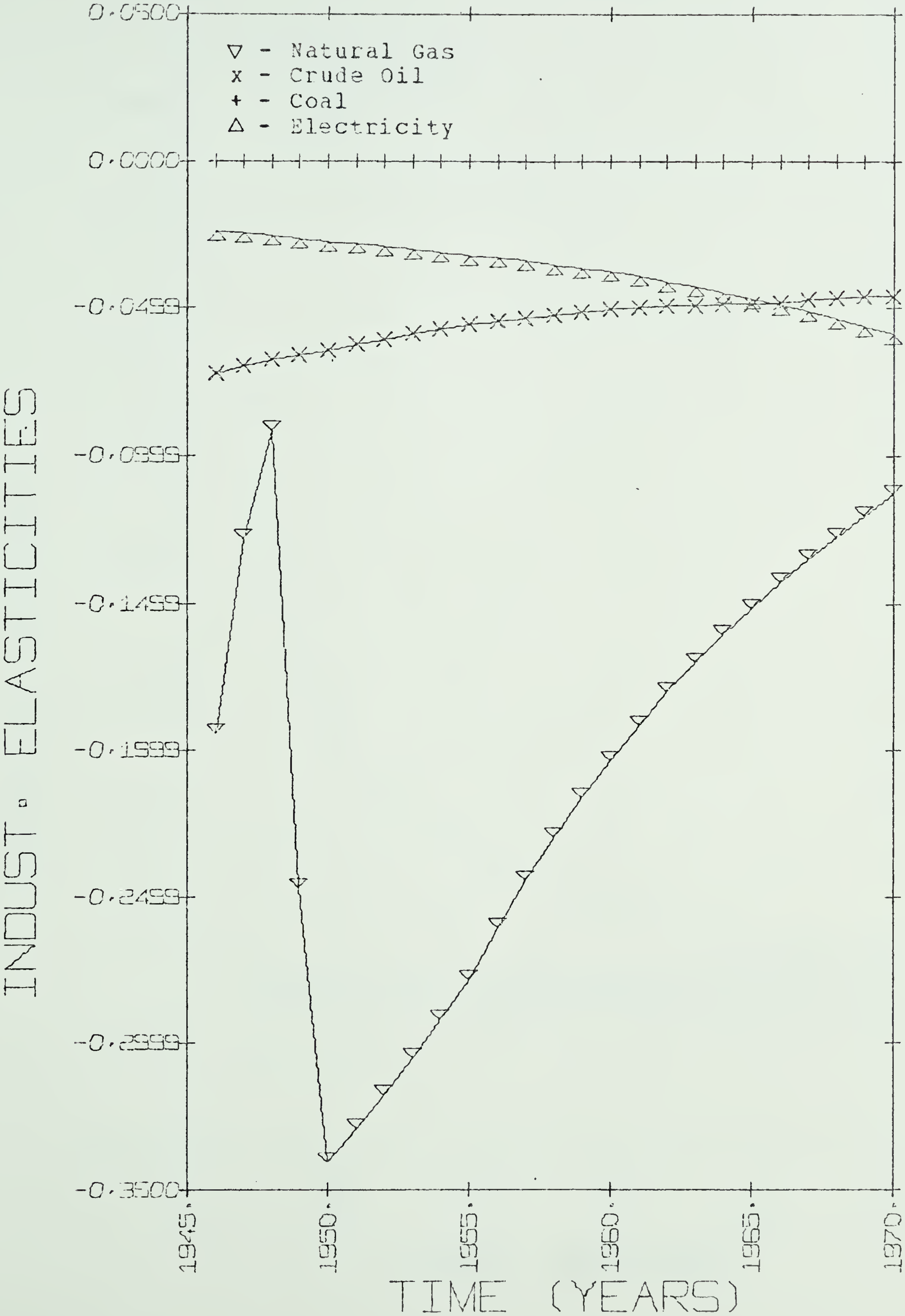

FIGURE IV.9 - ELASTICITY OF FREE DEMAND FOR INDUSTRIAL SECTOR, BASE CASE 1945-70.

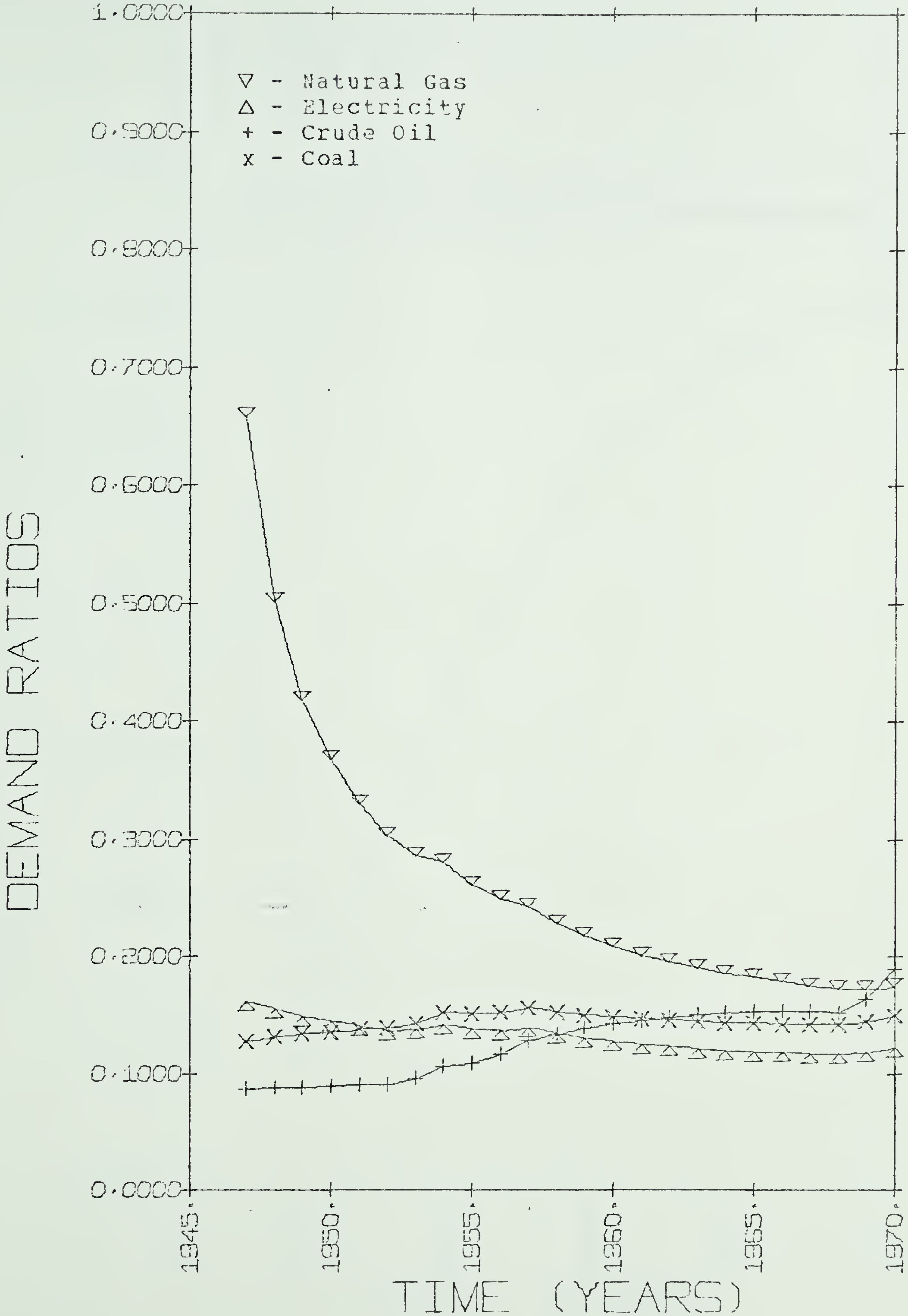

FIGURE IV.10 - RATIO OF FREE DEMAND TO TOTAL DEMAND FOR INDUSTRIAL SECTOR, BASE CASE 1945-70.

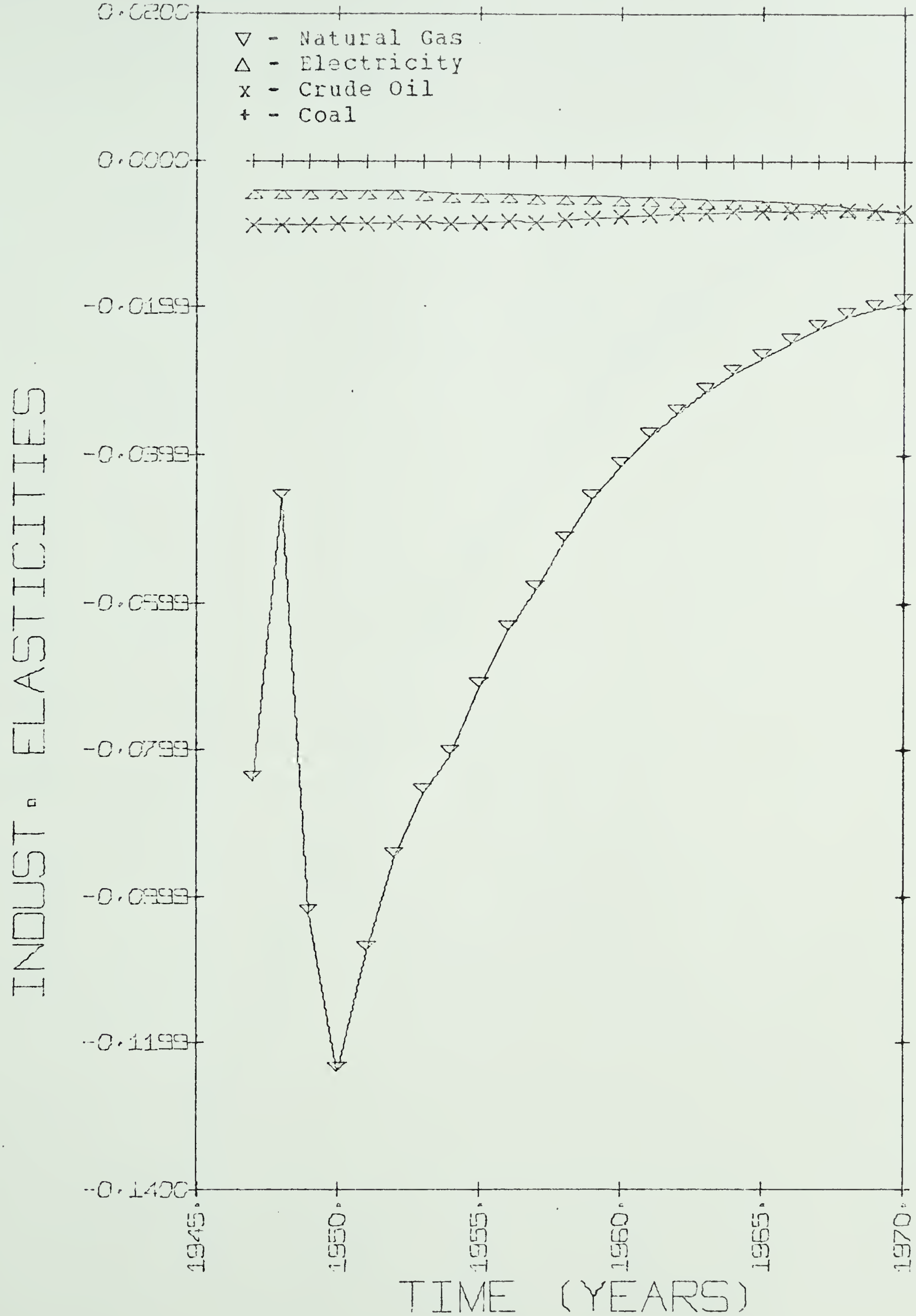

FIGURE IV.11 - ELASTICITY OF TOTAL DEMAND FOR INDUSTRIAL SECTOR, BASE CASE 1945-70.

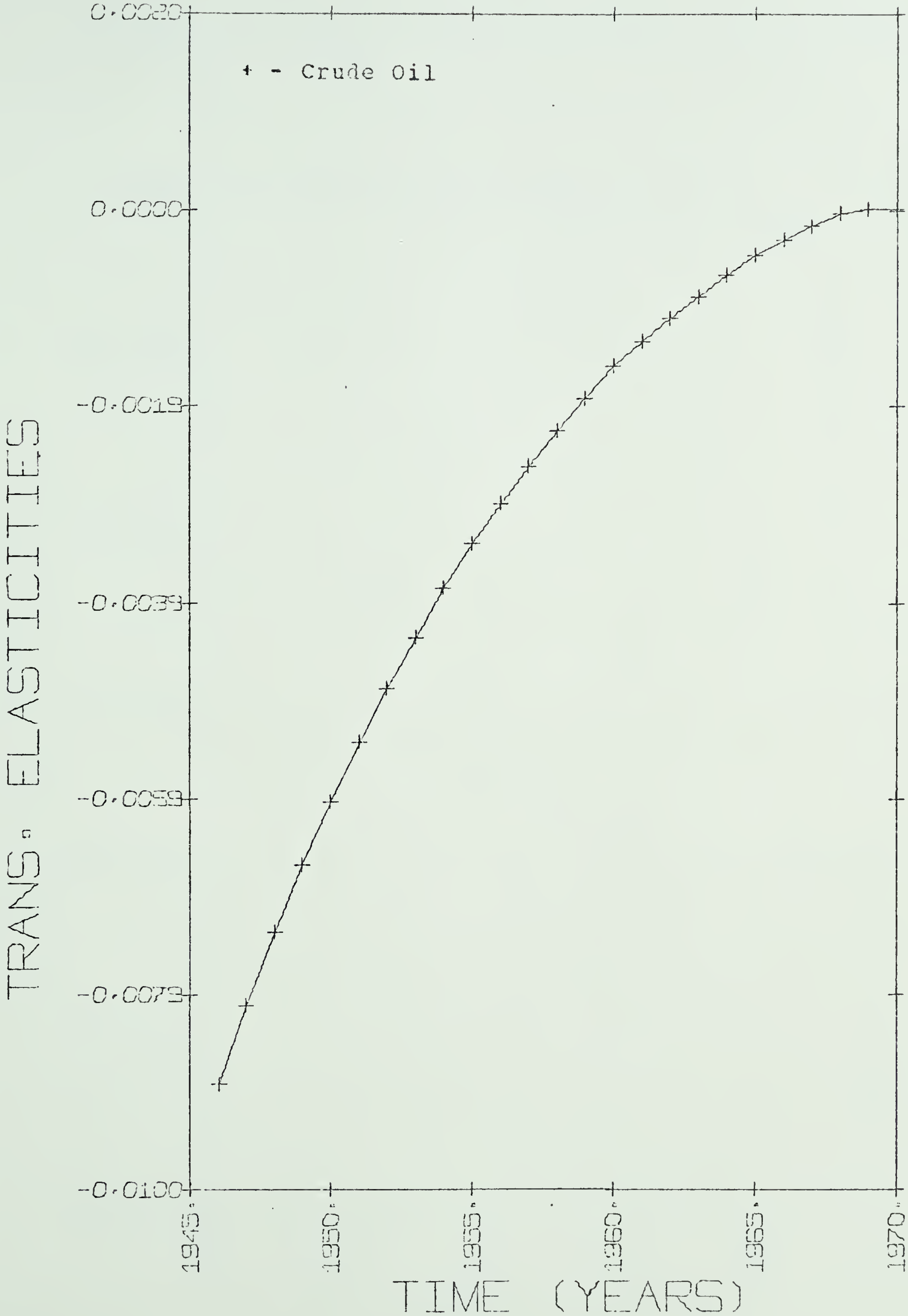

FIGURE IV.12 - ELASTICITY OF FREE DEMAND FOR TRANSPORTATION SECTOR, BASE CASE 1945-70.

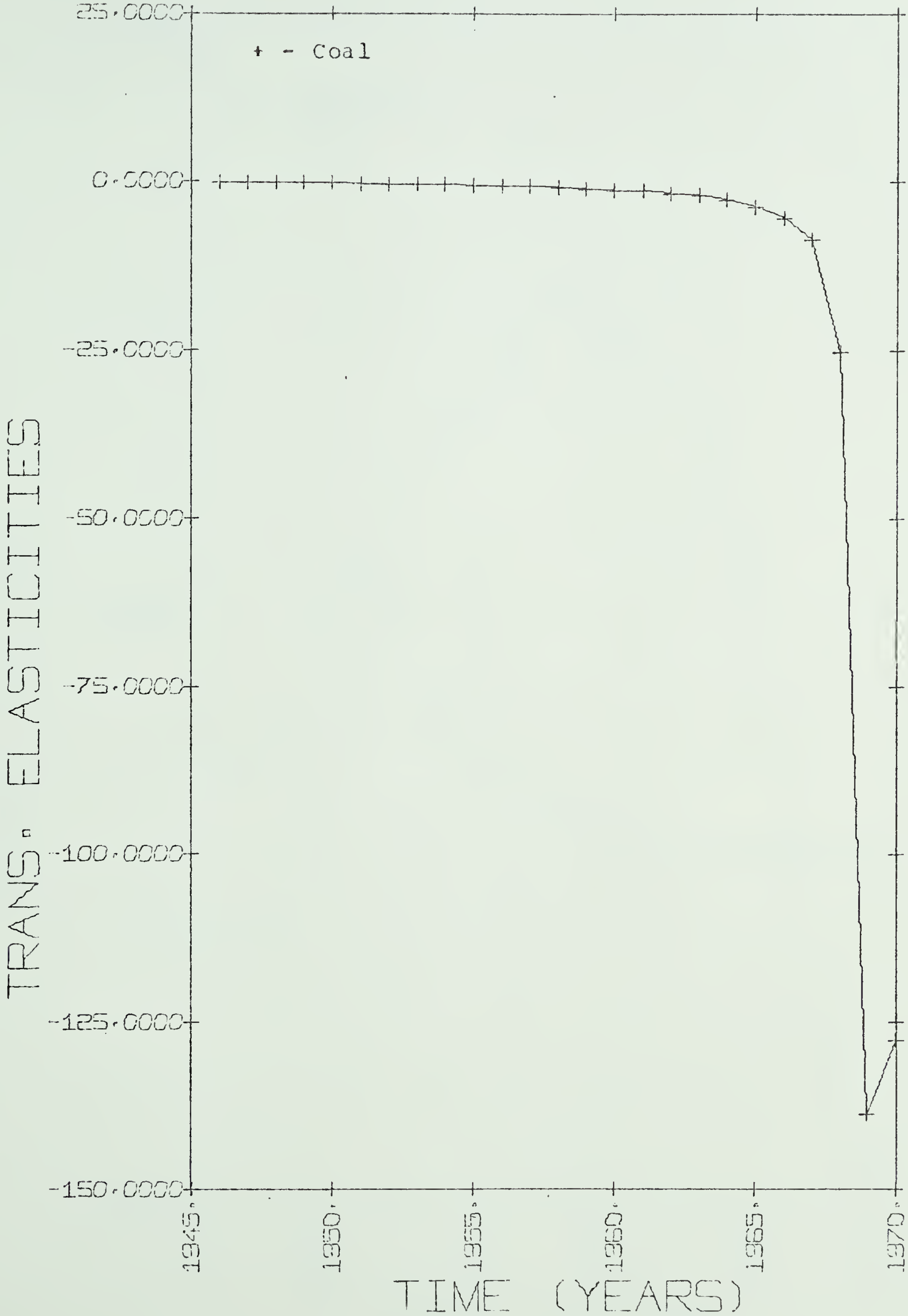

FIGURE IV.13 - ELASTICITY OF FREE DEMAND FOR TRANSPORTATION SECTOR, BASE CASE 1945-70.

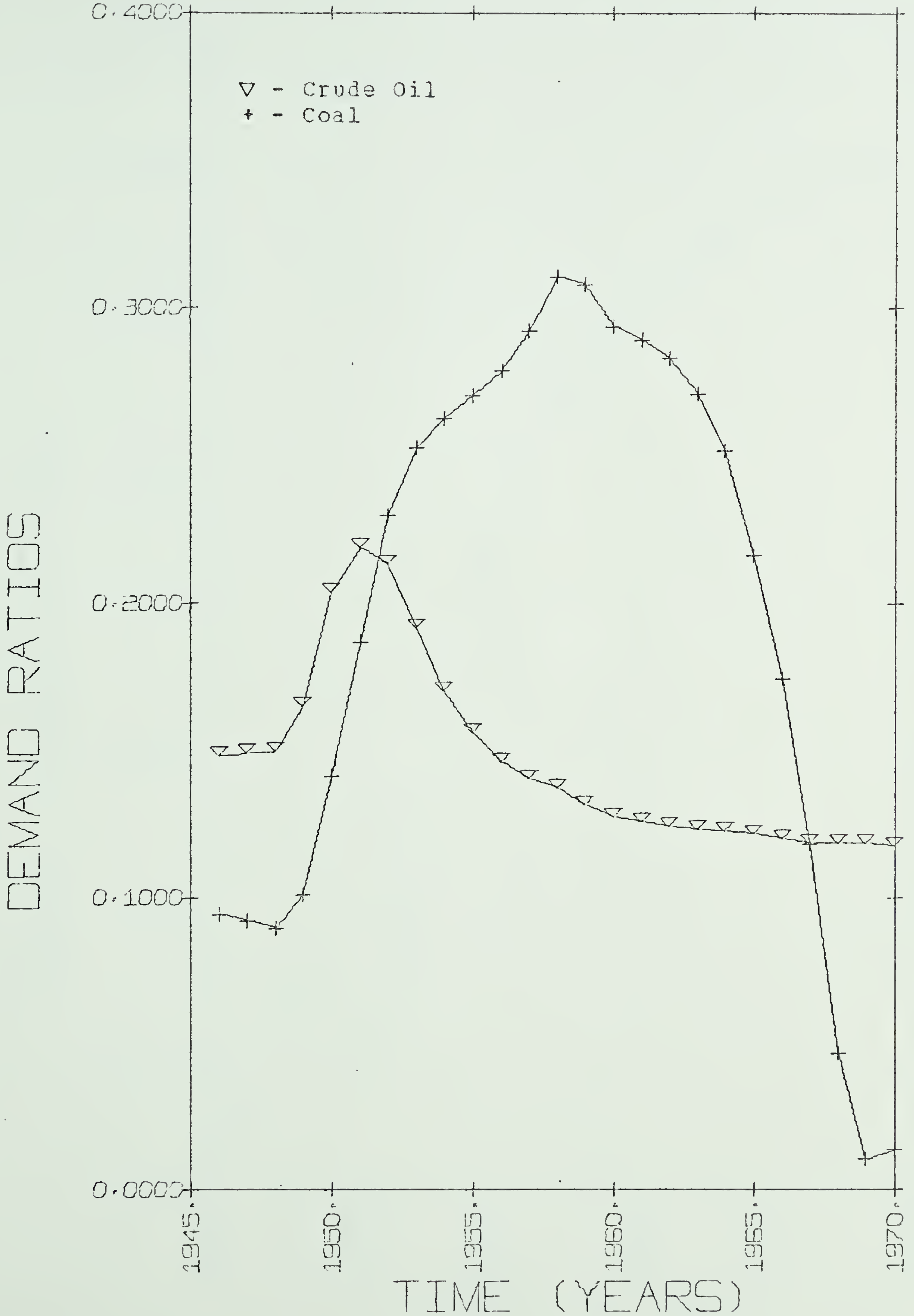

FIGURE IV.14 - RATIO OF FREE DEMAND TO TOTAL DEMAND FOR TRANSPORTATION SECTOR, BASE CASE 1945-70.

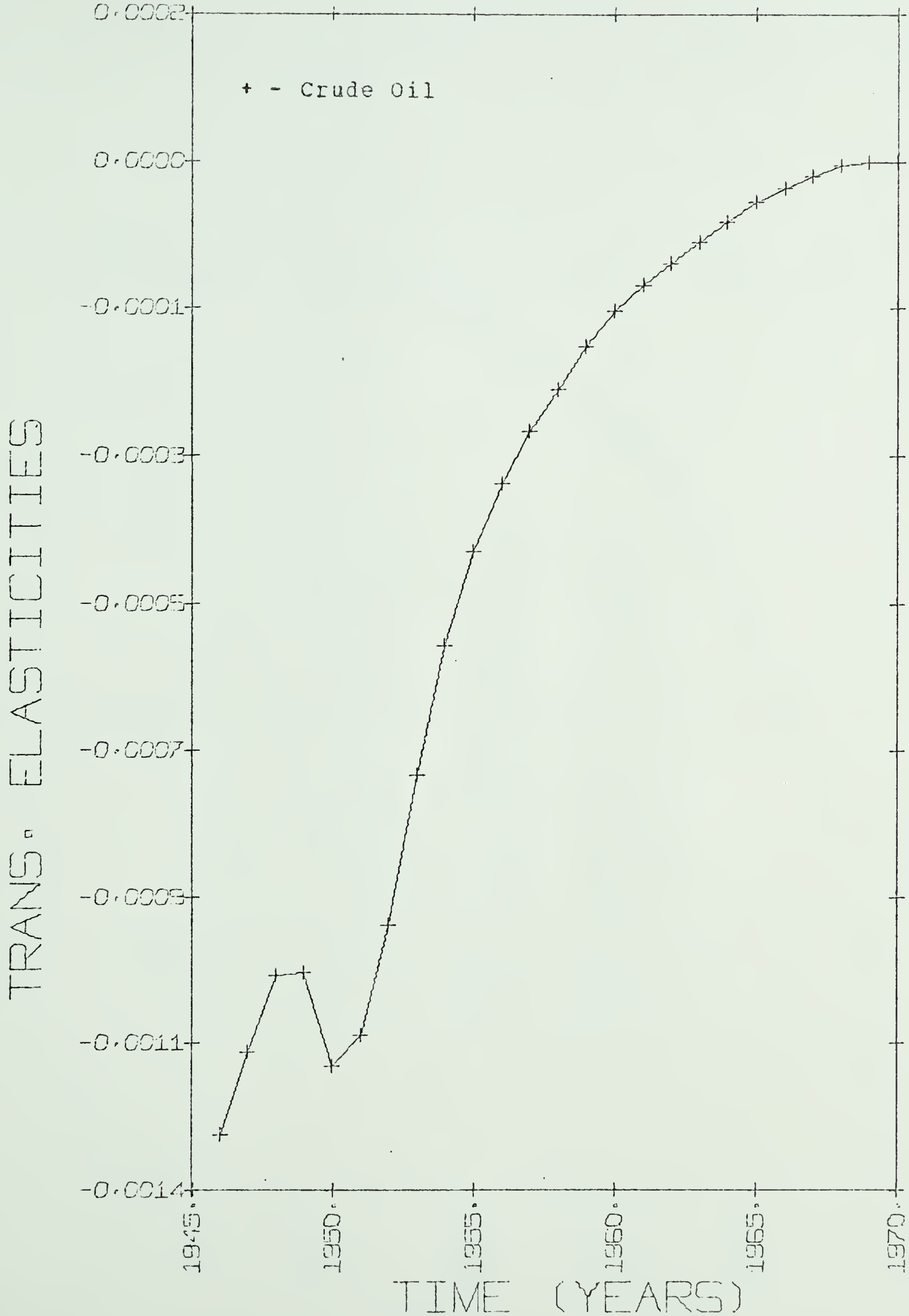

FIGURE IV.15 - ELASTICITY OF TOTAL DEMAND FOR TRANSPORTATION SECTOR, BASE CASE 1945-70.

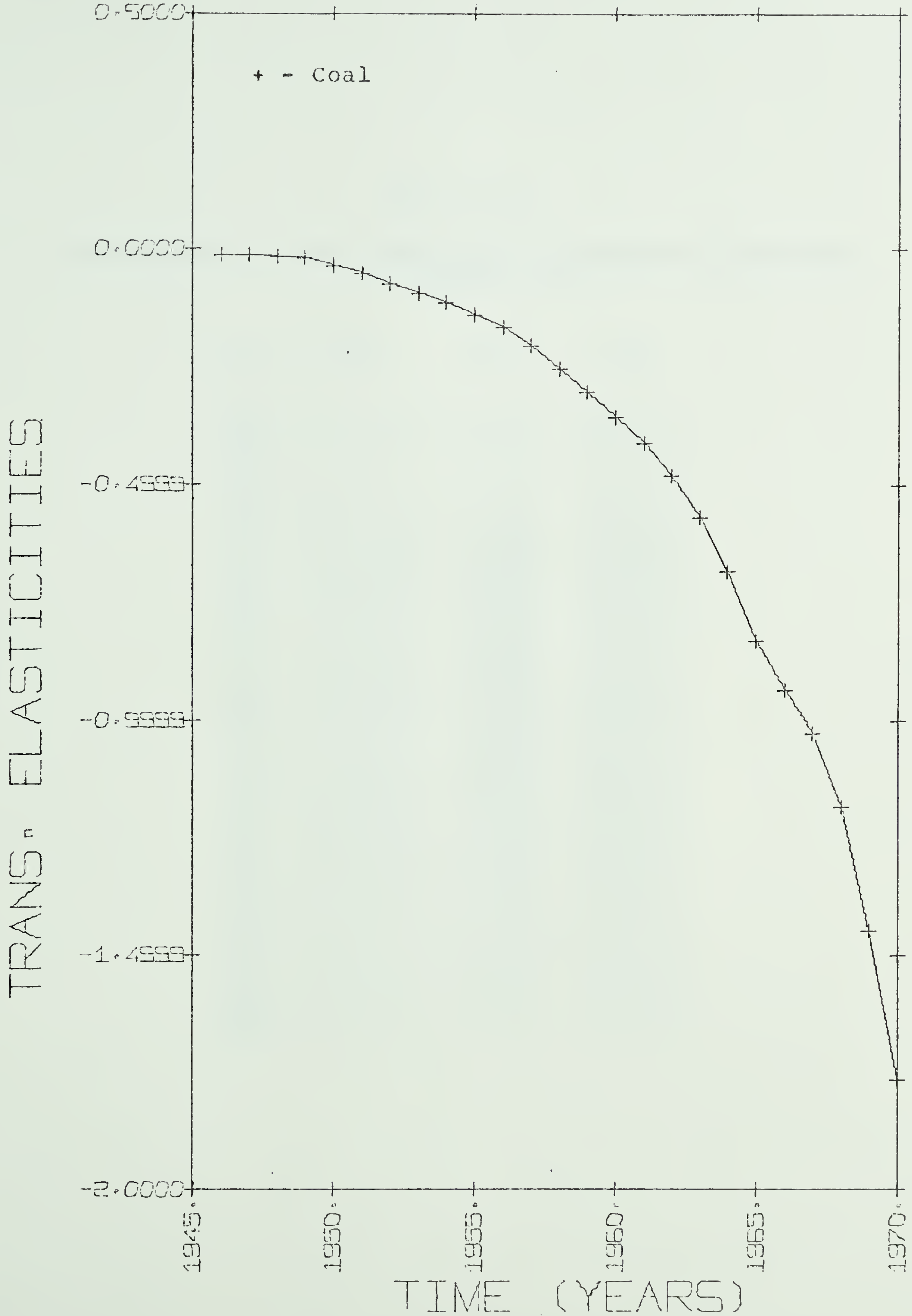

FIGURE IV.16 - ELASTICITY OF TOTAL DEMAND FOR TRANSPORTATION SECTOR, BASE CASE 1945-70.

TABLE IV.2

ELASTICITIES OF FREE DEMAND FOR ELECTRICITY GENERATING SECTOR

YEAR	COAL	GAS	OIL
1945	-------	-------	-------
1946	-------	-------	-------
1947	-------	-------	-------
1948	-------	-------	-------
1949	-------	-------	-------
1950	-0.4109	-0.9300	-0.0279
1951	-0.3700	-0.9019	-0.0278
1952	-0.3165	-0.8831	-0.0278
1953	-0.2515	-0.8607	-0.0277
1954	-0.1741	-0.8350	-0.0277
1955	-0.0836	-0.8062	-0.0277
1956	-0.0408	-0.7982	-0.0278
1957	-0.0369	-0.7919	-0.0279
1958	-0.0366	-0.7840	-0.0281
1959	-0.0363	-0.7745	-0.0282
1960	-0.0361	-0.7634	-0.0283
1961	-0.0347	-0.7623	-0.0288
1962	-0.0332	-0.7616	-0.0292
1963	-0.0319	-0.7593	-0.0297
1964	-------	-------	-------
1965	-0.0543	-0.7502	-0.0308
1966	-------	-------	-------
1967	-0.2122	-0.8630	-0.0314
1968	-------	-------	-------
1969	-------	-------	-------
1970	-------	-------	-------

TABLE IV.3

RATIO OF FREE DEMAND TO TOTAL DEMAND FOR ELECTRICITY GENERATING SECTOR

YEAR	COAL	GAS	OIL
1945	-----	-----	-----
1946	-----	-----	-----
1947	-----	-----	-----
1948	-----	-----	-----
1949	-----	-----	-----
1950	0.350	0.441	0.386
1951	0.290	0.410	0.334
1952	0.270	0.375	0.309
1953	0.490	0.596	0.528
1954	0.650	0.768	0.694
1955	0.710	0.855	0.752
1956	0.520	0.875	0.578
1957	0.460	0.561	0.476
1958	0.660	0.795	0.676
1959	0.650	0.769	0.656
1960	0.610	0.774	0.600
1961	0.700	0.738	0.692
1962	0.870	0.887	0.858
1963	0.930	0.923	0.905
1964	-----	-----	-----
1965	0.980	0.947	0.933
1966	-----	-----	-----
1967	1.000	0.868	0.919
1968	-----	-----	-----
1969	-----	-----	-----
1970	-----	-----	-----

TABLE IV.4

ELASTICITIES OF TOTAL DEMAND FOR ELECTRICITY GENERATING SECTOR

YEAR	COAL	GAS	OIL
1945	-------	-------	-------
1946	-------	-------	-------
1947	-------	-------	-------
1948	-------	-------	-------
1949	-------	-------	-------
1950	-0.1400	-0.4100	-0.0108
1951	-0.1100	-0.3690	-0.0093
1952	-0.0900	-0.3310	-0.0086
1953	-0.1200	-0.5130	-0.0146
1954	-0.1100	-0.6420	-0.0192
1955	-0.0600	-0.6890	-0.0208
1956	-0.0200	-0.6990	-0.0161
1957	-0.0200	-0.4440	-0.0133
1958	-0.0200	-0.6230	-0.0190
1959	-0.0200	-0.5950	-0.0185
1960	-0.0200	-0.5900	-0.0170
1961	-0.0200	-0.5630	-0.0199
1962	-0.0300	-0.6750	-0.0251
1963	-0.0300	-0.7010	-0.0269
1964	-------	-------	-------
1965	-0.0500	-0.7110	-0.0288
1966	-------	-------	-------
1967	-0.2100	-0.7490	-0.0288
1968	-------	-------	-------
1969	-------	-------	-------
1970	-------	-------	-------

C. PROJECTIONS

One major application of quantitative models is making future projections. These projections may be conducted in order to measure the impact of changes in policy (controllable) variables. On the other hand, projections may be made on the basis of expected future behavior of uncontrollable variables with the objective of determining critical areas upon which government policy must focus.

An infinite number of projections exist which could be performed by the 'Canadian Interfuel Substitution Model' under an equal number of hypotheses. Some of the interesting projections would include hypothesized future scenarios of fuel prices, sector growth rates, commitment liberation rates, fossil capacity fraction, the quantity of electricity produced from hydro, and numerous combinations of these scenarios.

However, since the prime purpose here is simply to demonstrate possible uses of the model, only three key cases will be dealt with. These three cases will attempt to measure the implications of two different future price scenarios and two different commitment liberation rate scenarios. The justification for choosing these scenarios includes:

- the sector growth rates are not fundamental to determining the extent or nature of the interfuel

substitution process. Therefore, no new insights will result from varying the sector growth rates.

- both the fossil capacity fraction (FCF) and the quantity of electricity produced from hydro (ZFH) have already been determined for the intermediate time range (10-15 years) in terms of financial committments. Radical changes would be required to alter these programs significantly.

- Canada is currently in a situation of high uncertainty with regard to future expected fuel prices and hence commitment liberation rates. Therefore, a keen interest exists concerning the future reactions to possible price movements.

The time span employed for the projections is fifteen years. Since the 'Canadian Interfuel Substitution Model' claims to produce quantitative, as well as qualitative accuracy, it was felt that projections to the year 1985 would properly satisfy these claims.

CASE 1

The CASE 1 Projection is based on the following future scenarios of the exogenous variables.

1. Primary demand sector growth rates - maintained equal to those that existed for the period 1945-70.

2. Fossil capacity fraction (FCF) - based on estimates by the Department of Energy, Mines and Resources[1,2].

3. Quantity of electricity produced from hydro (ZFH) - based on estimates by the Department of Energy, Mines and Resources[1,3].

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[1] Department of Energy, Mines and Resources An Energy Policy for Canada Ottawa Vol. II, pg. 292.
[2] see Figure IV.17.
[3] see Figure IV.18.

4. Fuel prices - assume that the price of oil and gas in 1985 will triple the average price that existed in 1970[1].

Coal prices will rise significantly but not at the same rate as oil or gas prices. Electricity prices will increase moderately in response to slightly higher nuclear generation costs. However, these rising electricity costs are expected to reach a new and very stable plateau shortly after 1985.

5. Primary sector consumer commitment liberation rates - maintained at the 1970 values of the Base Case.

The results of the Case 1 projections are presented in Figures IV.21 to IV.27.

The fuel price scenarios hypothesized represent a large decline in the relative price of electricity while the relative prices of the fossil fuels remain effectively constant.

Although the responses of the residential-commercial sector[2] and the electricity generating sector correspond with the price ratio changes that occured, it appears that the industrial sector[3] has been dominated by the behavior of the variable TIME (i.e. those factors other than relative

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[1] see Figures IV.19 and IV.20 for the projected prices and price ratios.
[2] see Figure IV.22.
[3] see Figure IV.23.

fuel prices that affect market share behavior) in the distribution multipliers. Despite its lower relative price, the electricity market share of the industrial sector is rapidly replaced by natural gas and crude oil in their respective orders of significance. The results of the Case 2 Projections further discuss the problem of the non-price factors in the fuel selection process.

The transportation sector[1], and particularily the demand for crude oil, has been, in the past, very insensitive to price changes. Currently, and in the foreseeable future, there are no effective substitutes for crude oil in this sector.

The behavior of the electricity generating sector is dependent on the primary demand sector requirements for electricity. However, regardless of the behavior of the primary demand sectors, there is a trend in the electricity generating sector towards a larger market share for nuclear produced electricity[2]. This trend exists by specification of the exogenous model inputs.

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[1] see Figure IV.24.
[2] see Figure IV.26.

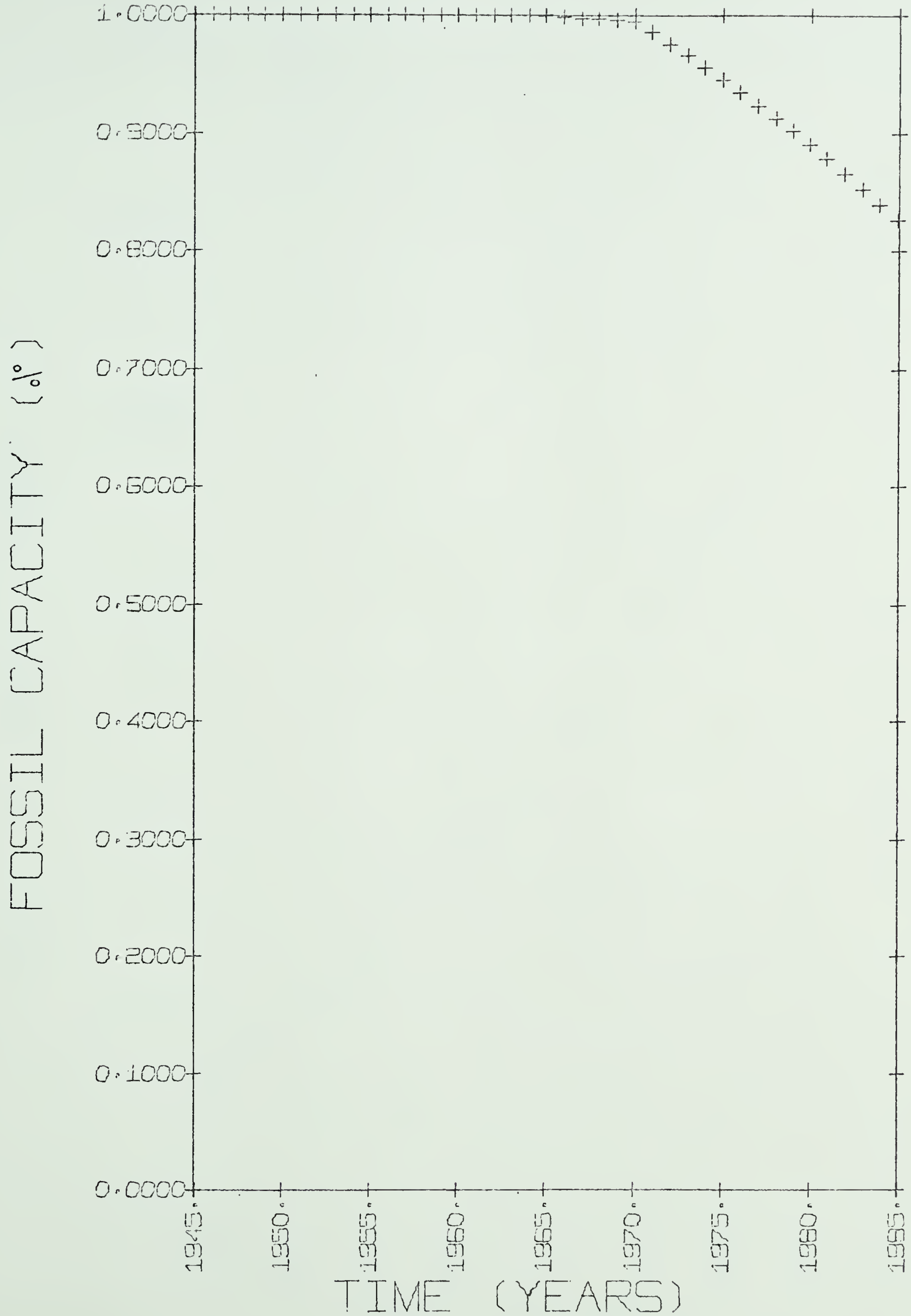

FIGURE IV.17 - PERCENTAGE OF TOTAL ELECTRICAL GENERATING CAPACITY WHICH IS DEPENDENT ON NON-NUCLEAR FUEL, CASE I 1945-85.

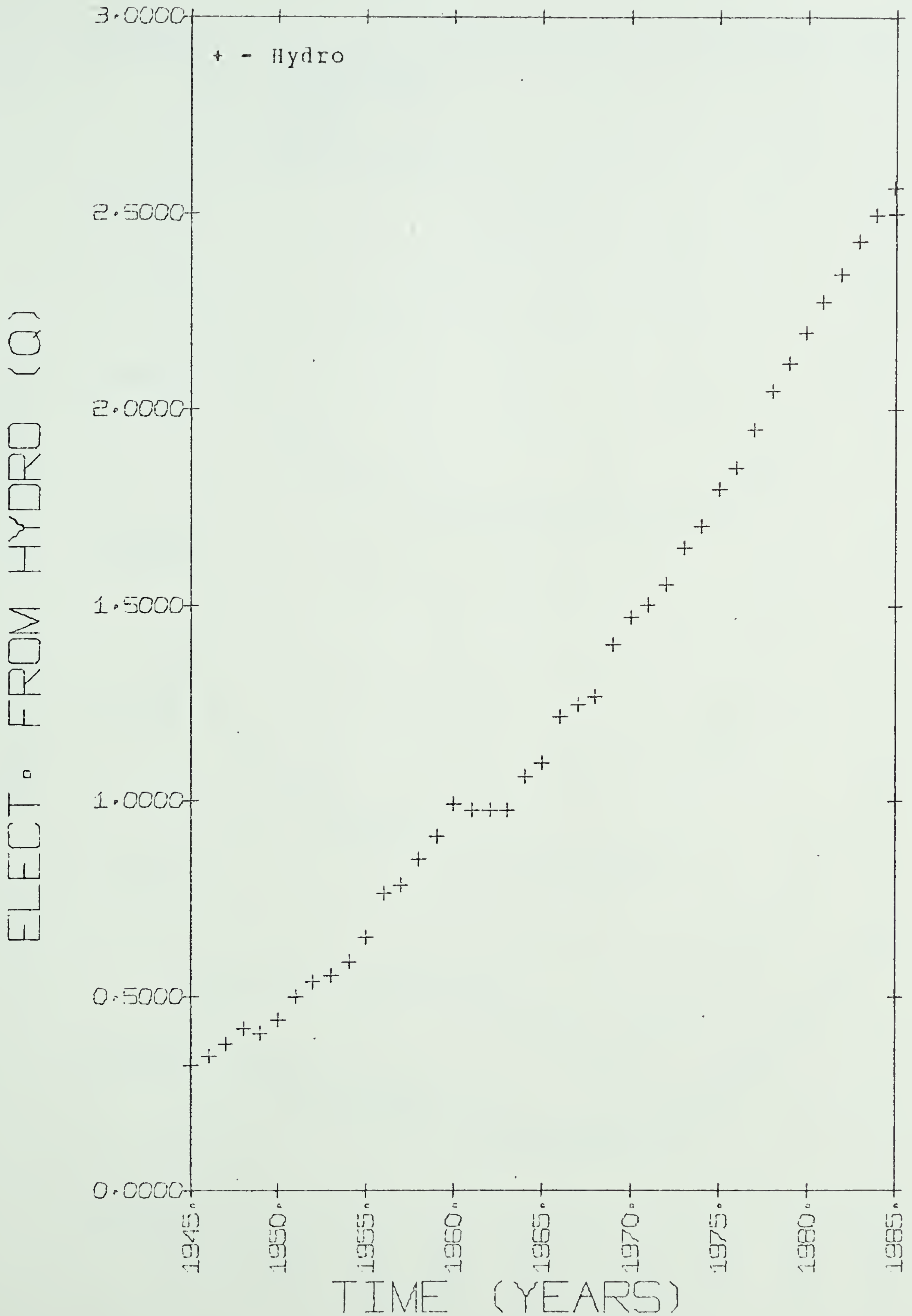

FIGURE IV.18 - ELECTRICITY GENERATED FROM HYDRO, CASE I 1945-85.

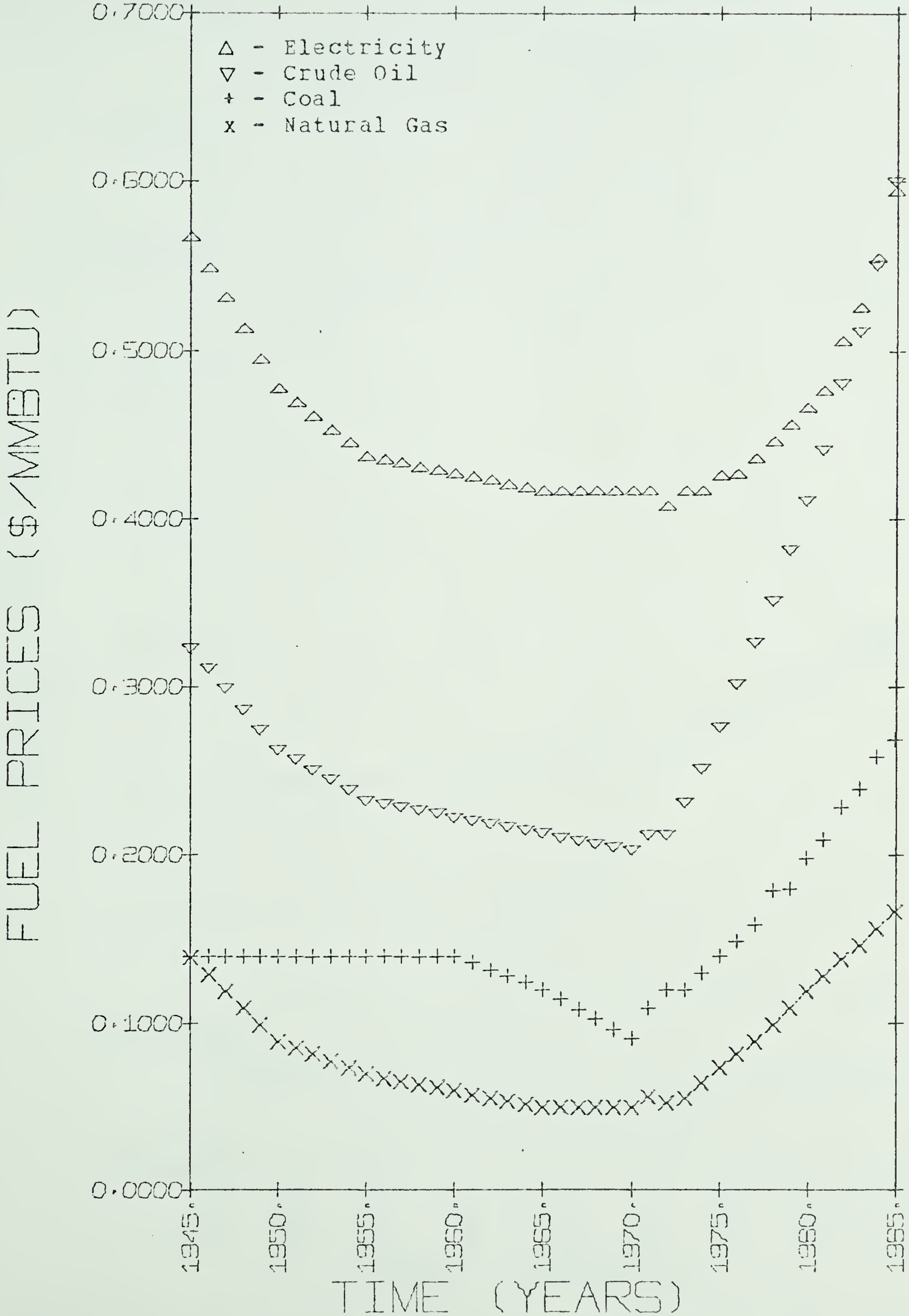

FIGURE IV.19 - FUEL PRICES, CASE I 1945-85.

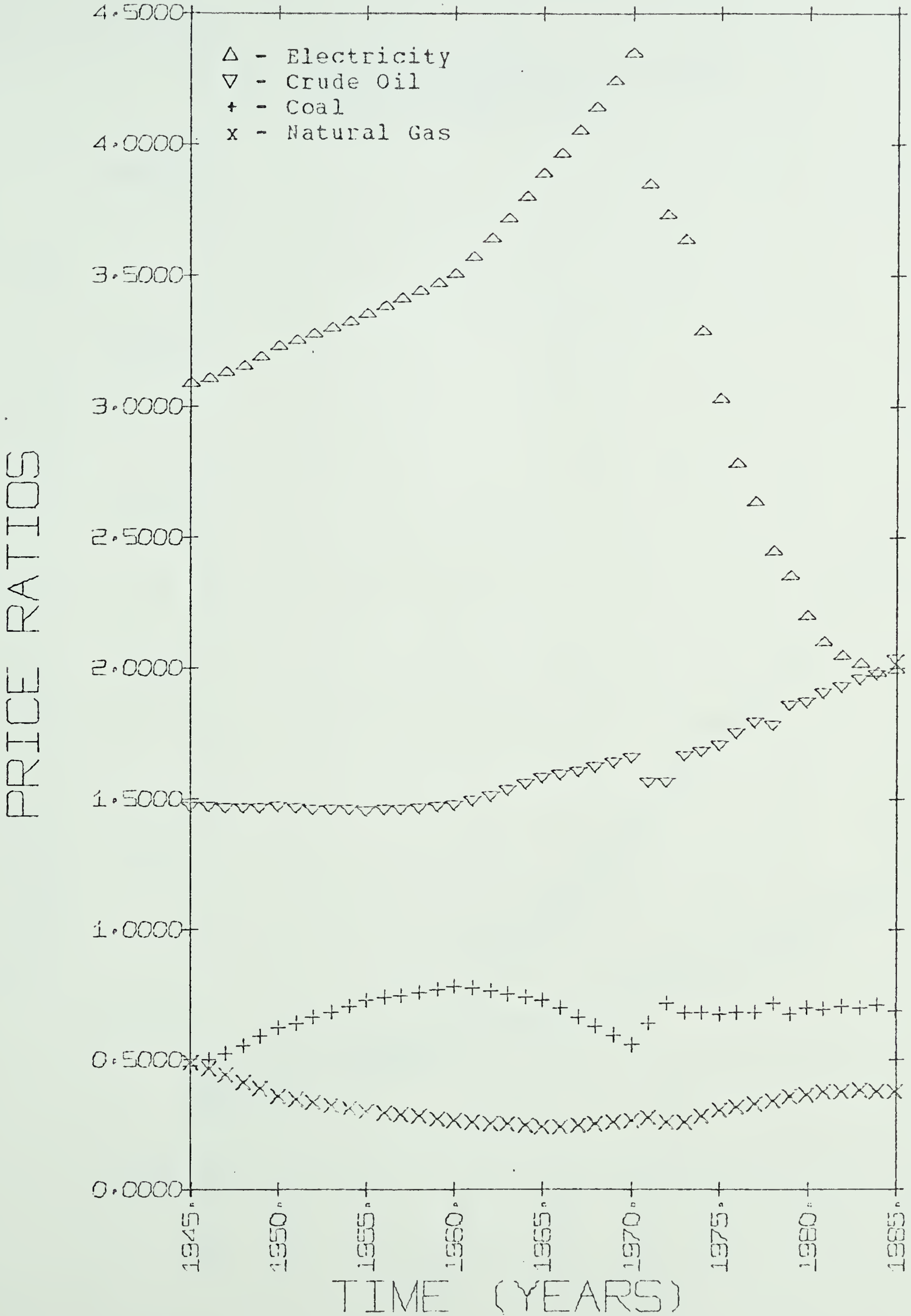

FIGURE IV.2? - RELATIVE PRICES OF THE FUEL FORMS, CASE I 1945-85.

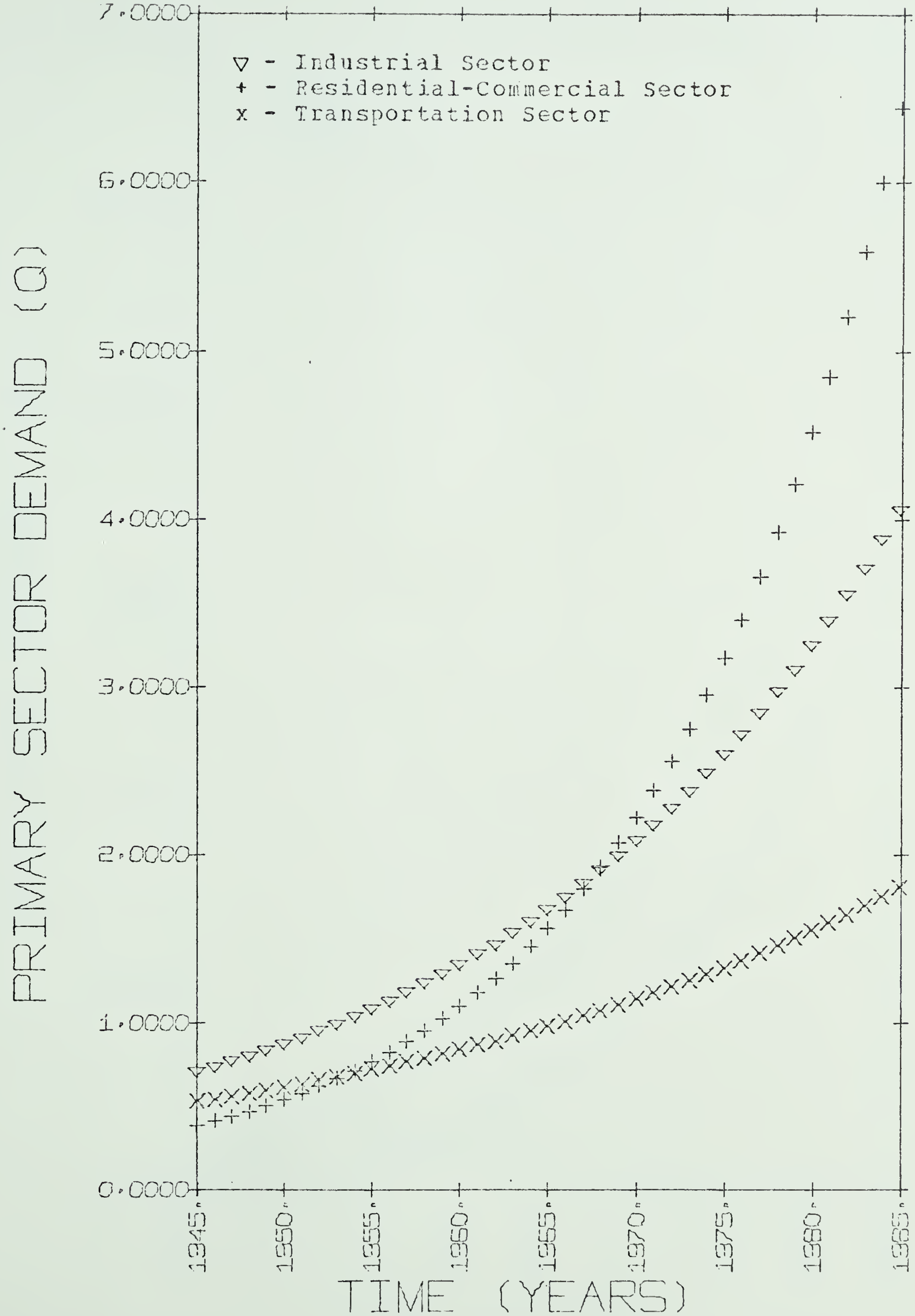

FIGURE IV.21 - ENERGY DEMAND BY THE PRIMARY CONSUMING SECTORS, CASE I 1945-85.

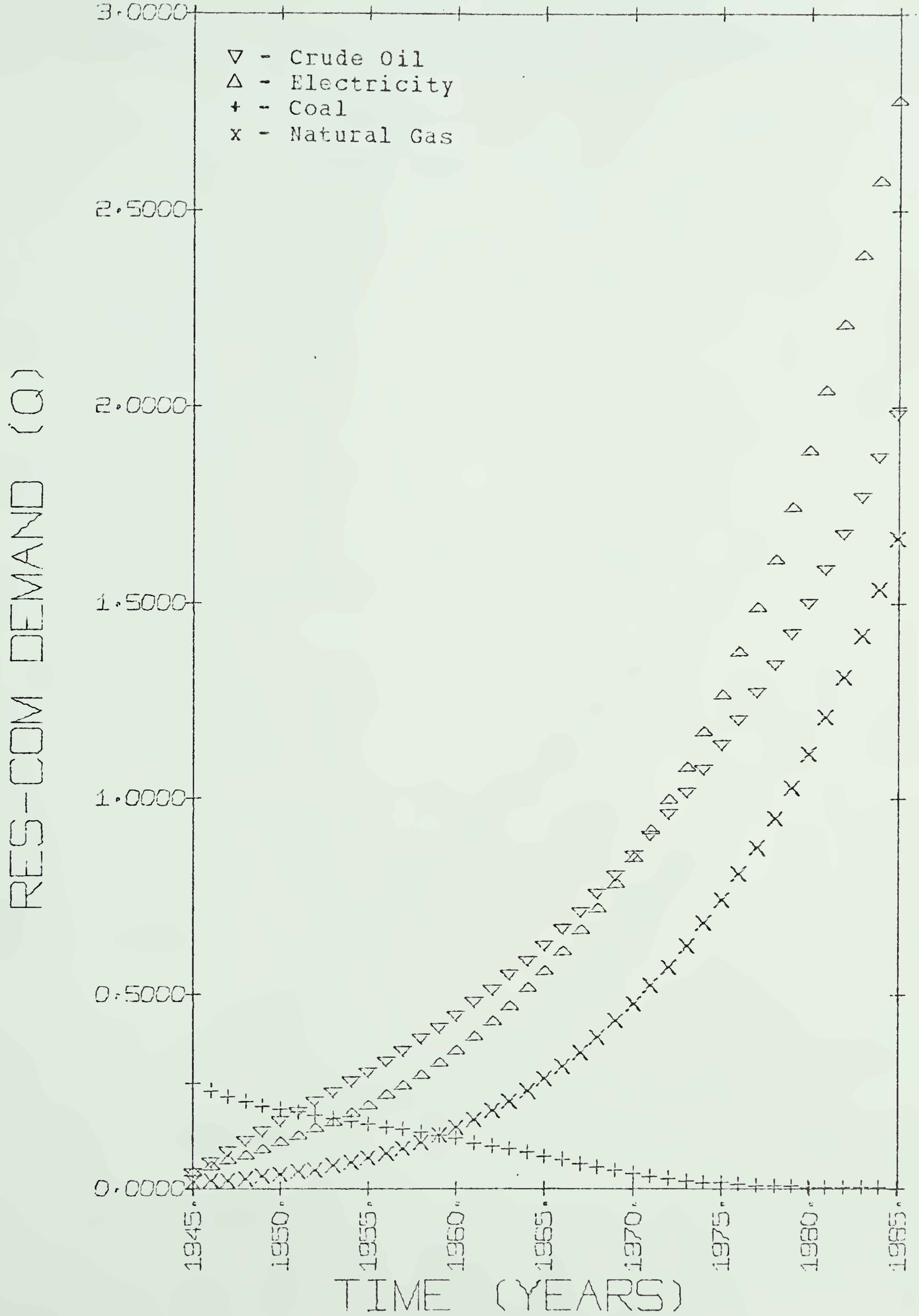

FIGURE IV.22 - RESIDENTIAL-COMMERCIAL DEMAND, CASE I 1945-85.

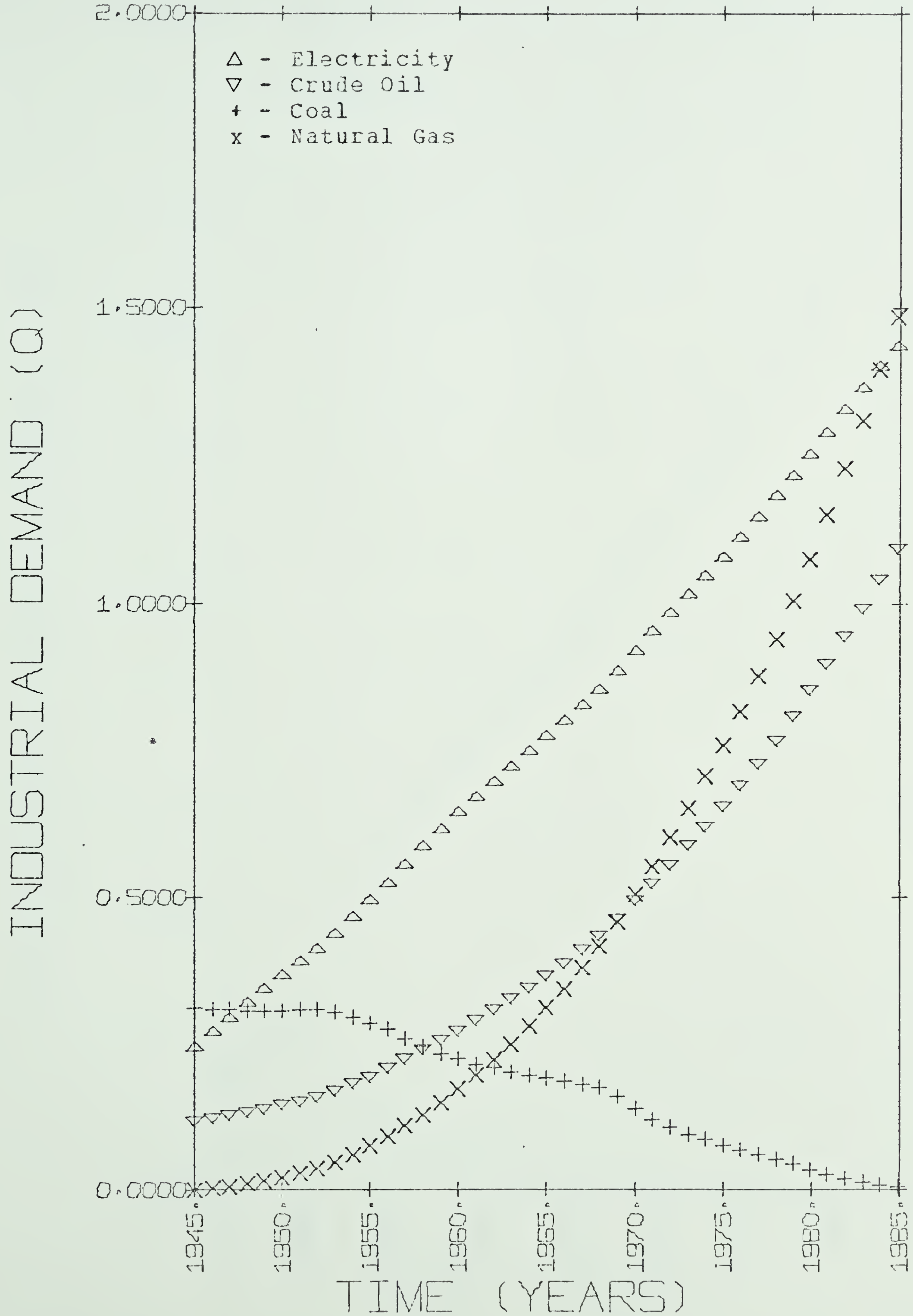

FIGURE IV.23 - INDUSTRIAL DEMAND, CASE I 1945-85.

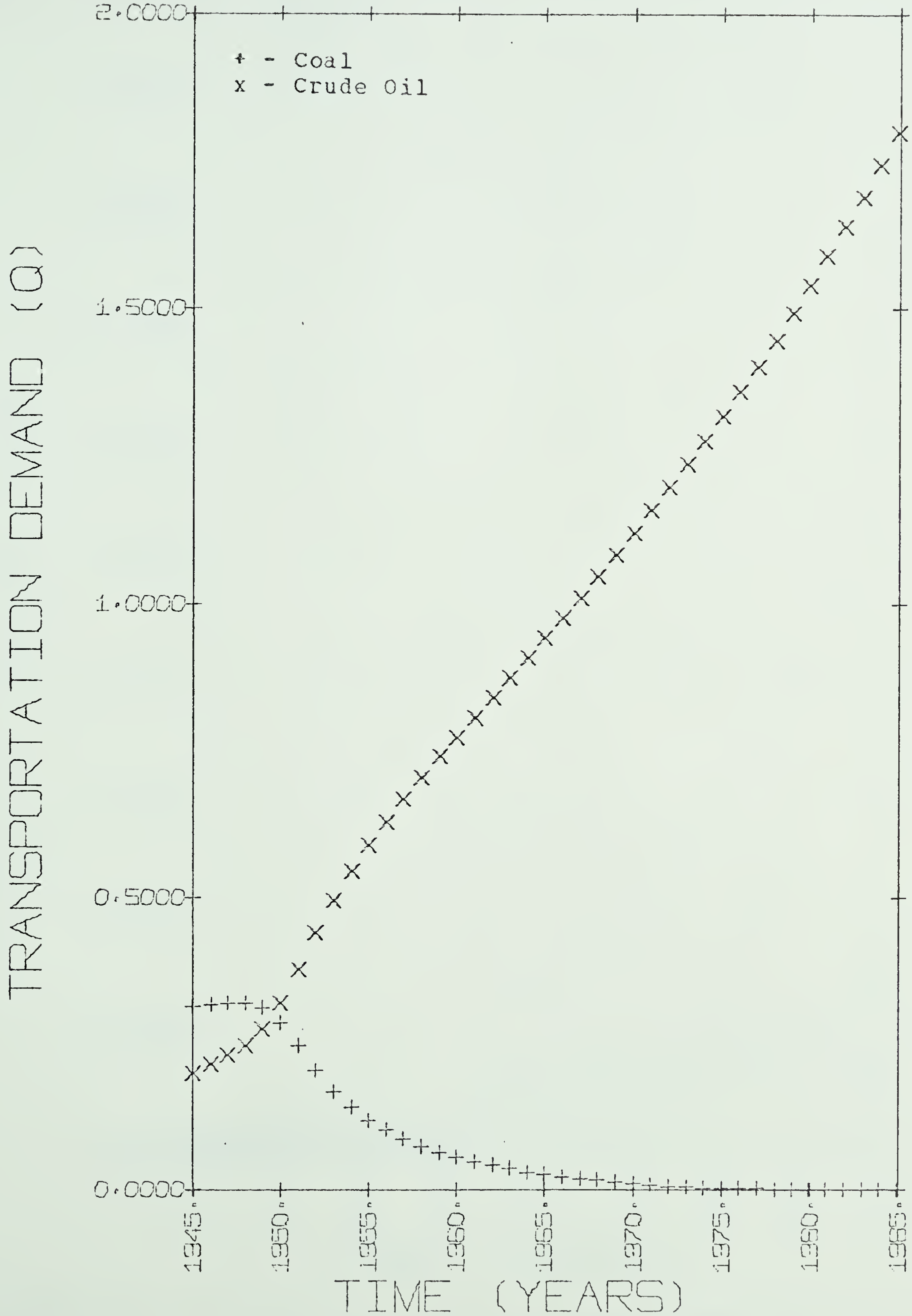

FIGURE IV.24 - TRANSPORTATION DEMAND, CASE I 1945-85.

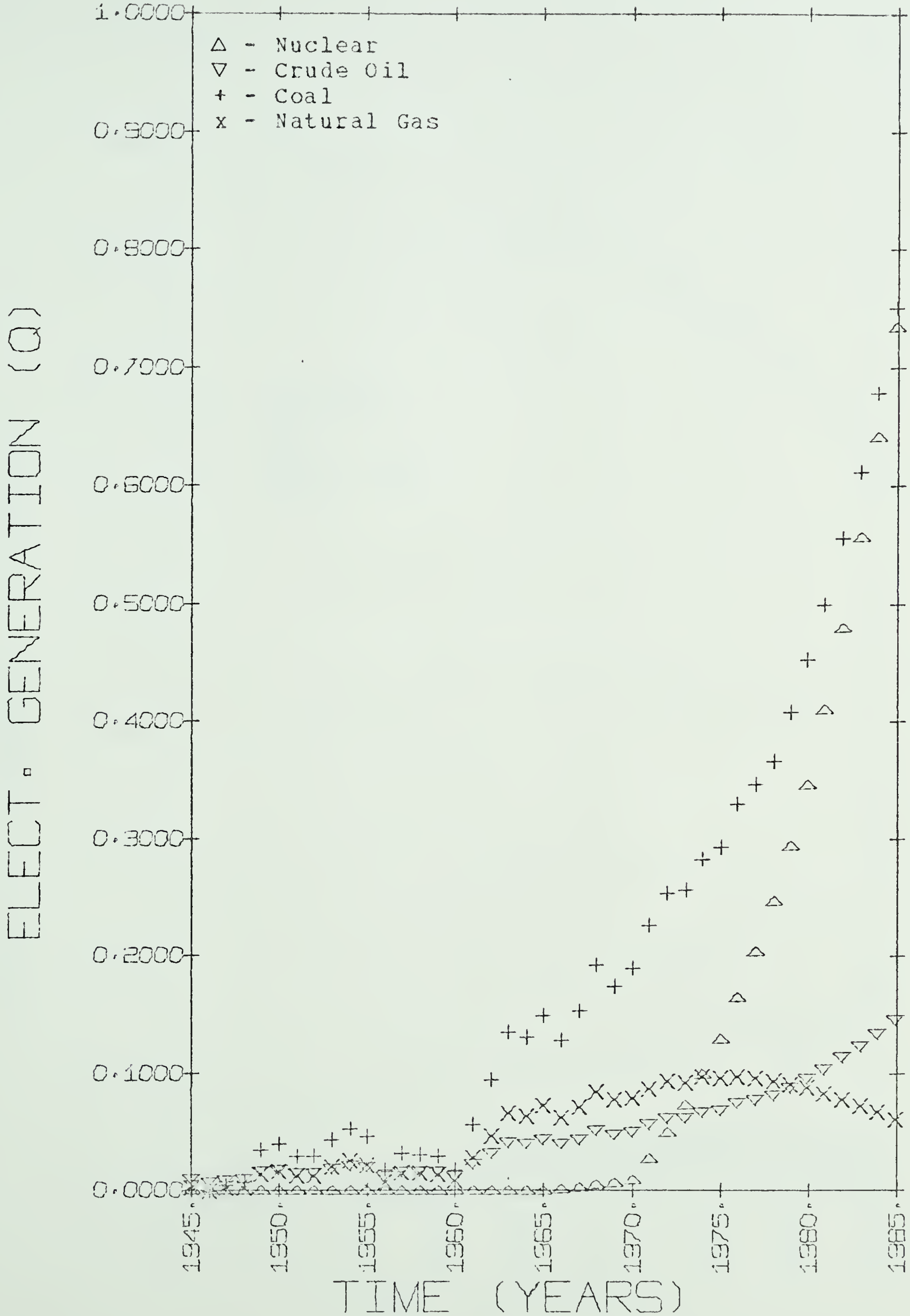

FIGURE IV.25 - ELECTRICITY GENERATED FROM PRIMARY FUEL FORMS, CASE I 1945-85.

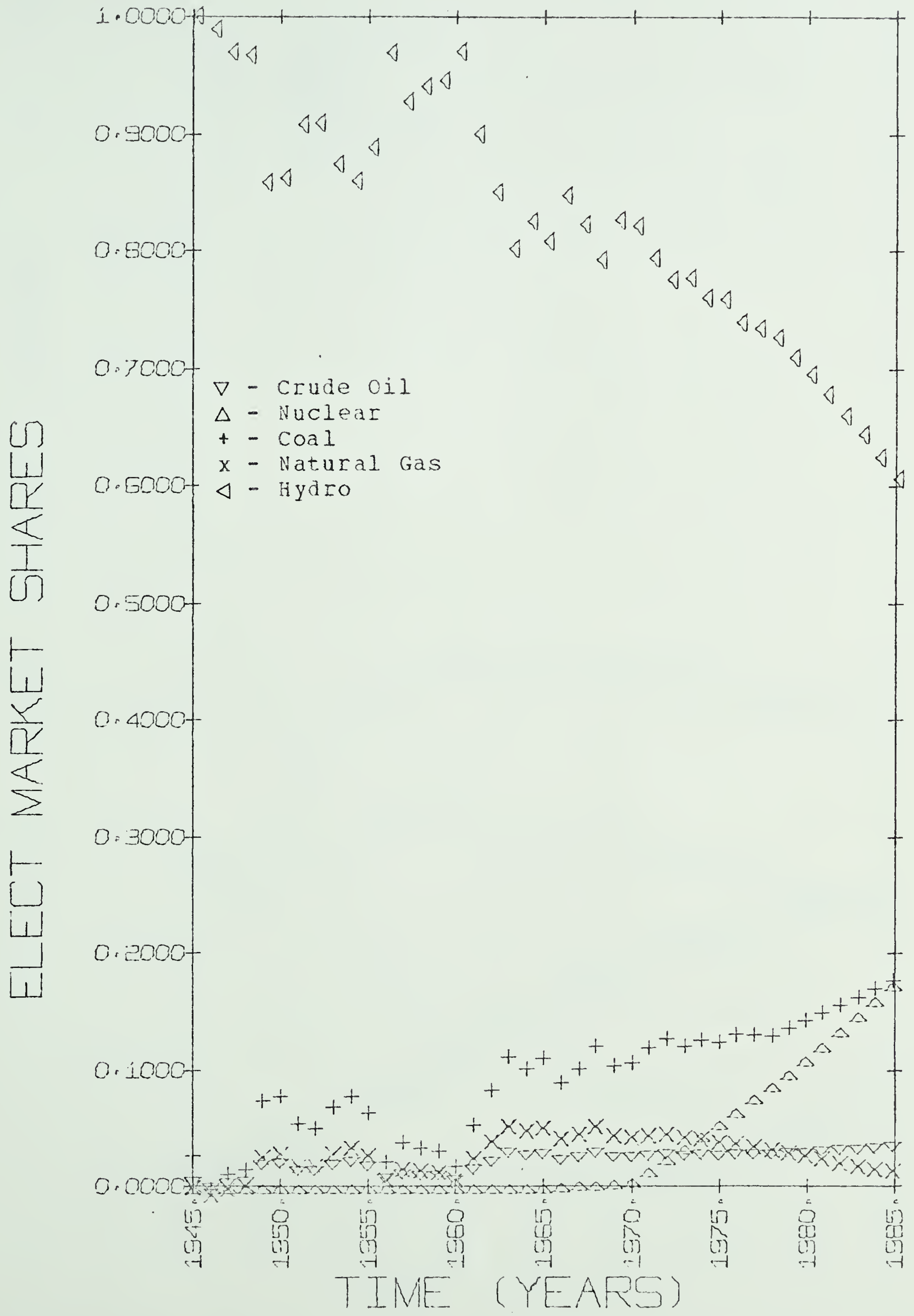

FIGURE IV.26 - PRIMARY FUEL MARKET SHARES IN THE ELECTRICITY GENERATING SECTOR, CASE I 1945-85.

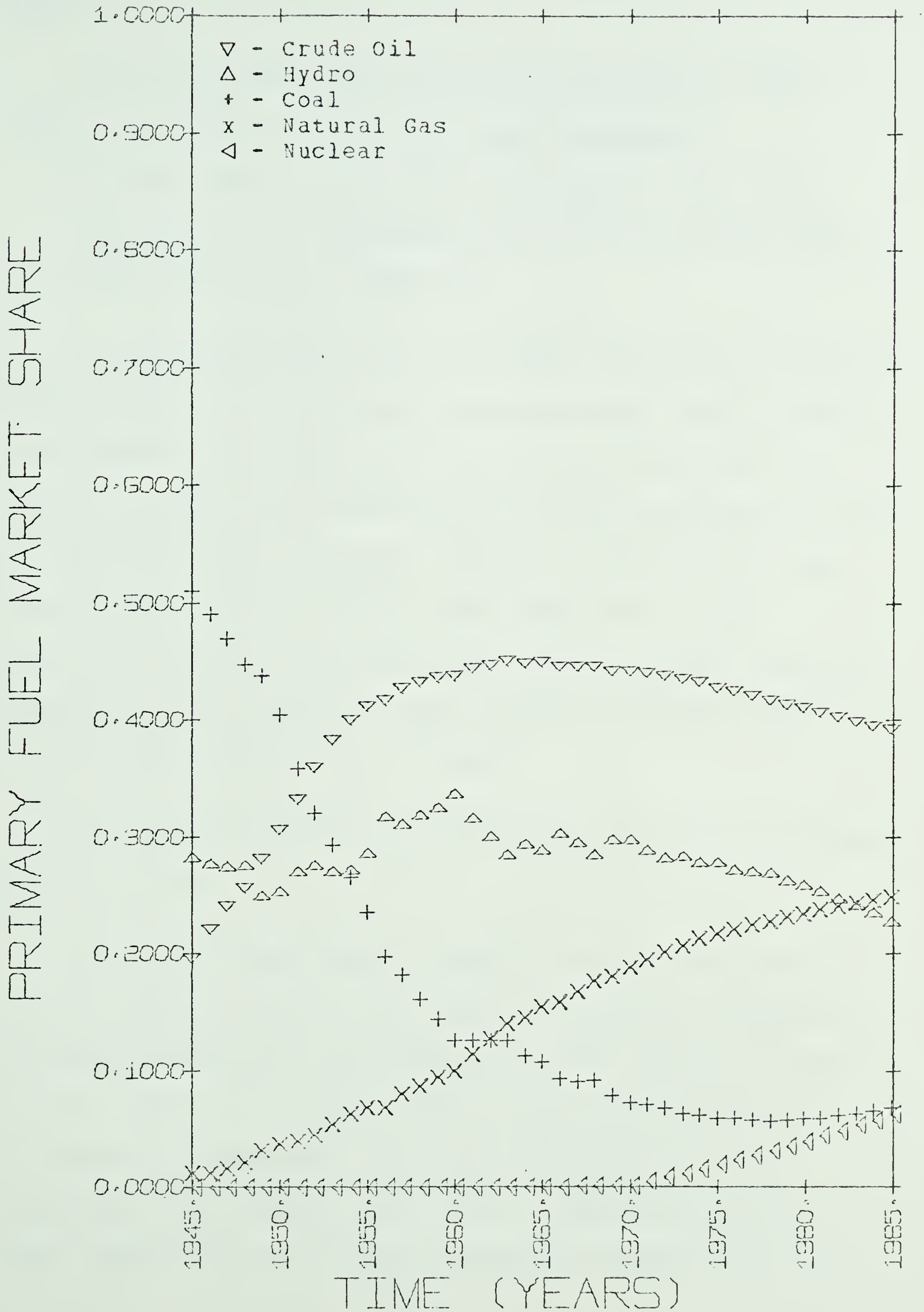

FIGURE IV.27 - PRIMARY FUEL MARKET SHARES FOR TOTAL CANADIAN ENERGY CONSUMPTION, CASE I 1945-85.

CASE 2

This case study adopts the same scenarios as CASE 1 with the exception of the fuel price scenarios.

1. Fuel prices - this case extrapolates the 1945-70 fuel prices and completely ignores the unstable fuel price situation of 1973-74[1].

The motivation of this case study consists of examining the sensitivity of the total interfuel substitution process to different price scenarios and thereby illustrate the degree to which the expectations of policy analysts may vary as different price scenarios unfold. In other words, does the inclusion of the 1973-74 fuel price data in the projection process significantly alter the policy analysts' expectations of the future with regards to energy demand and the interfuel substitution process?

The results of this projection are contained in Figures IV.30 to IV.38.

Analysis of the results reveal that the variation in price scenarios produces virtually no noticeable changes in the model projections. The reason for this result is due to the fact that the variable TIME, in the distribution multipliers, receives an increasing weighting as time progresses. This result would tend to indicate that the price sensitivity of the fuel selection process declines

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[1] see Figures IV.28 and IV.29.

relative to other factors as time increases. In spite of the fact that these non-price factors may be powerful, it is not logical to expect the demand for a fuel to become independent of its price, particulararily if fuel prices increase rapidly relative to other commodity prices. Unfortunately, however, there is no real basis for adjusting the coefficient of the variable TIME until this variable has been disaggregated and understood in its most basic form.

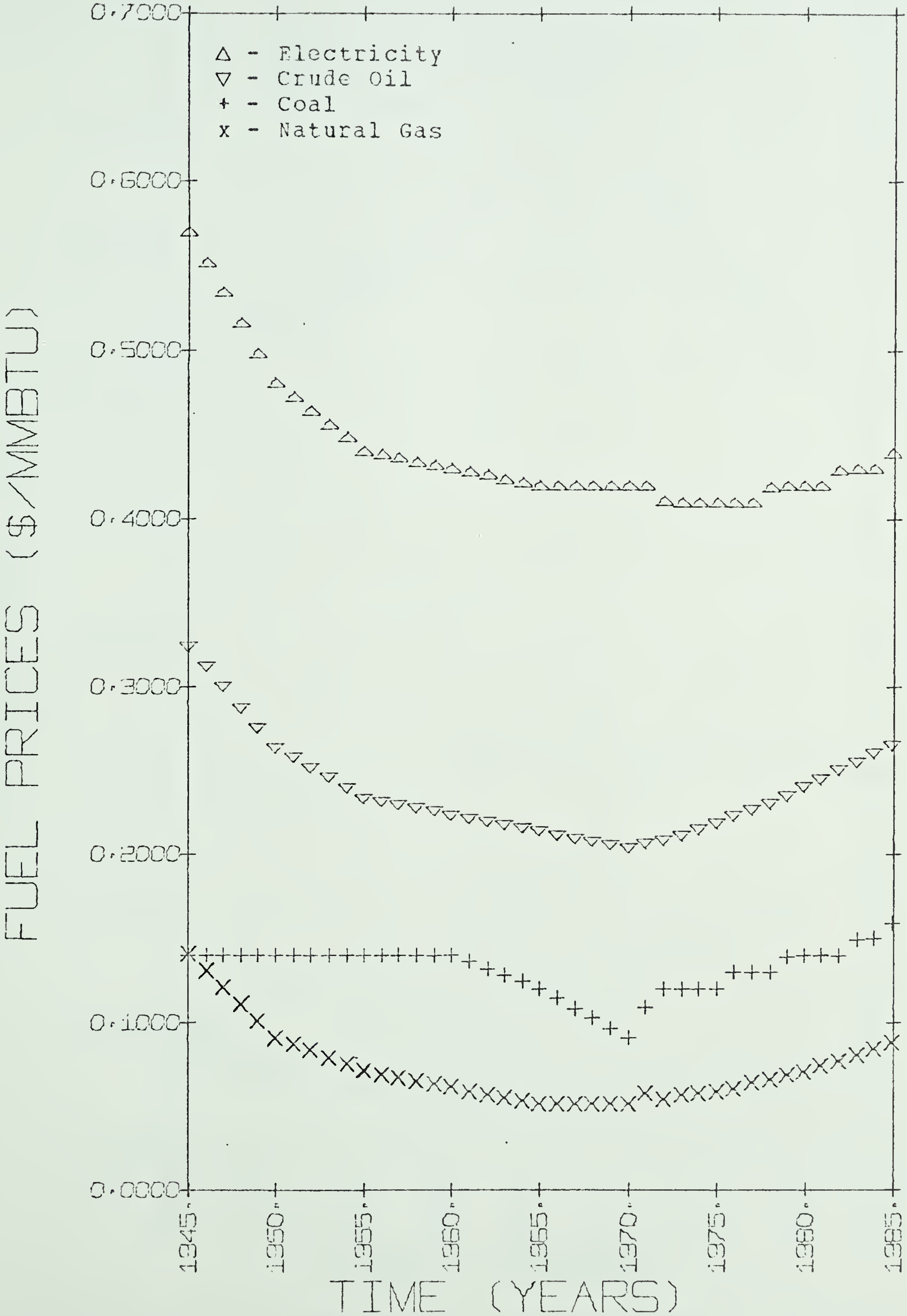

FIGURE IV.28 - FUEL PRICES, CASE II 1945-85.

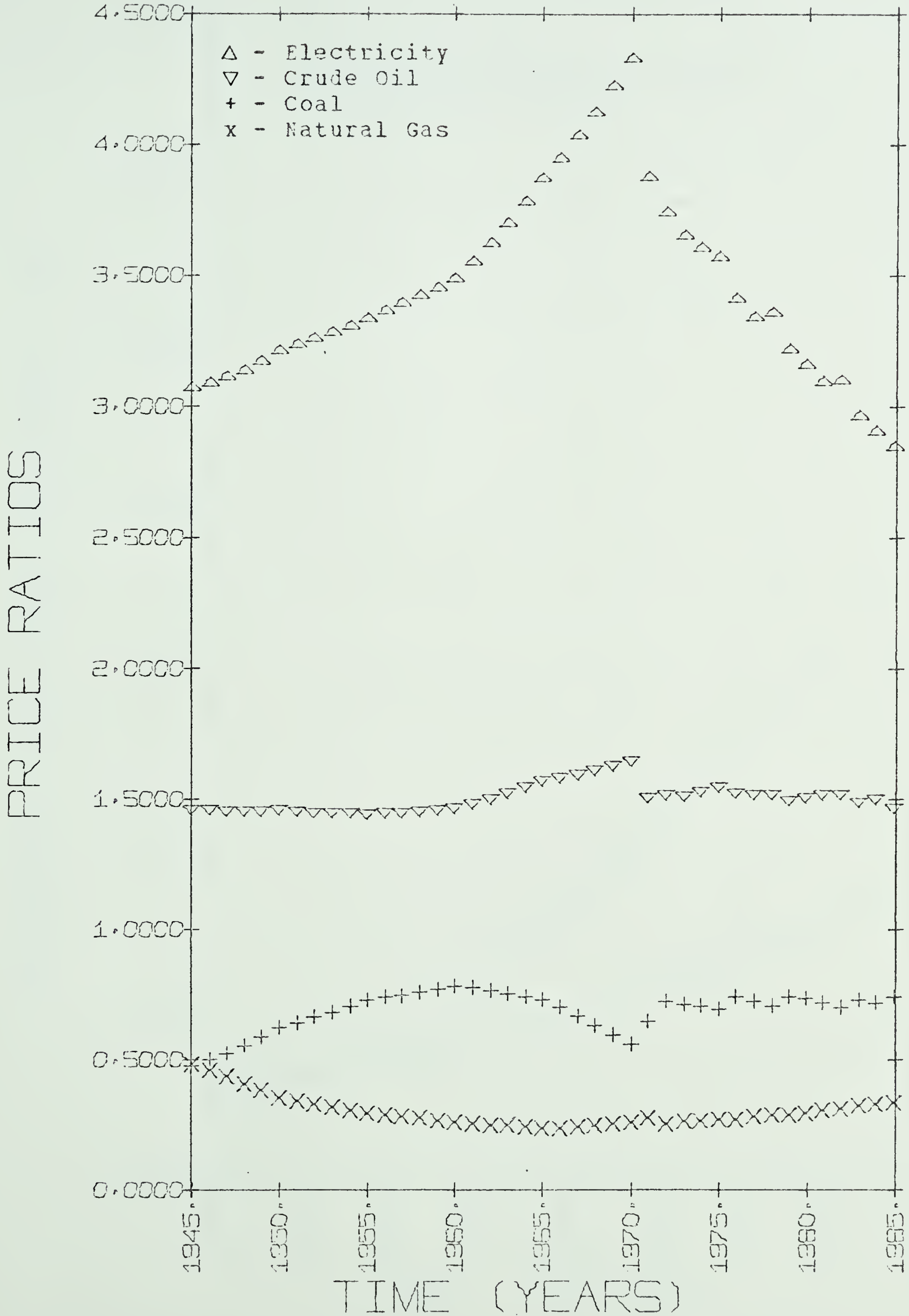

FIGURE IV.29 - RELATIVE PRICES OF THE FUEL FORMS, CASE II 1945-85.

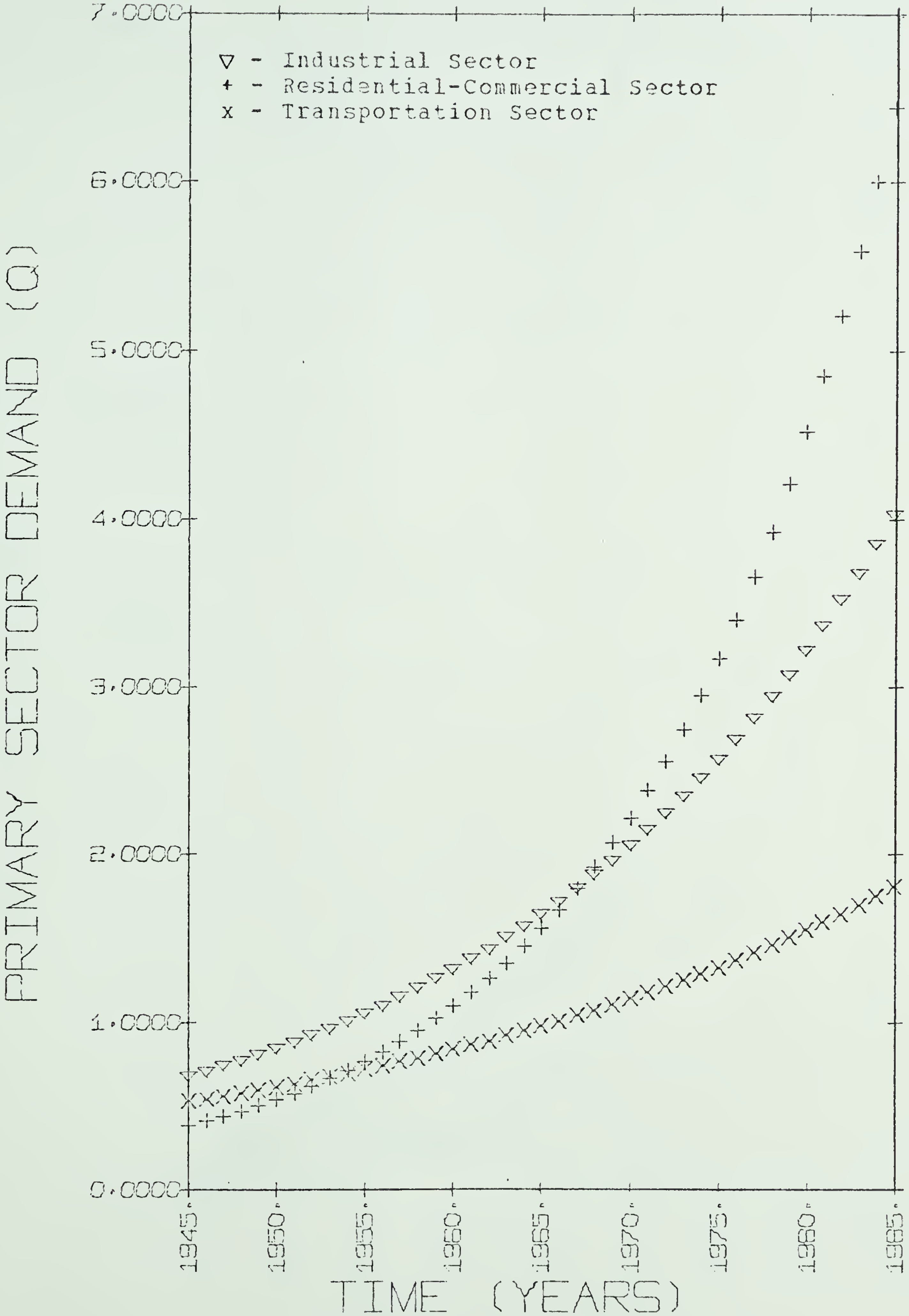

FIGURE IV.30 - ENERGY DEMAND BY THE PRIMARY CONSUMING SECTORS, CASE II 1945-85.

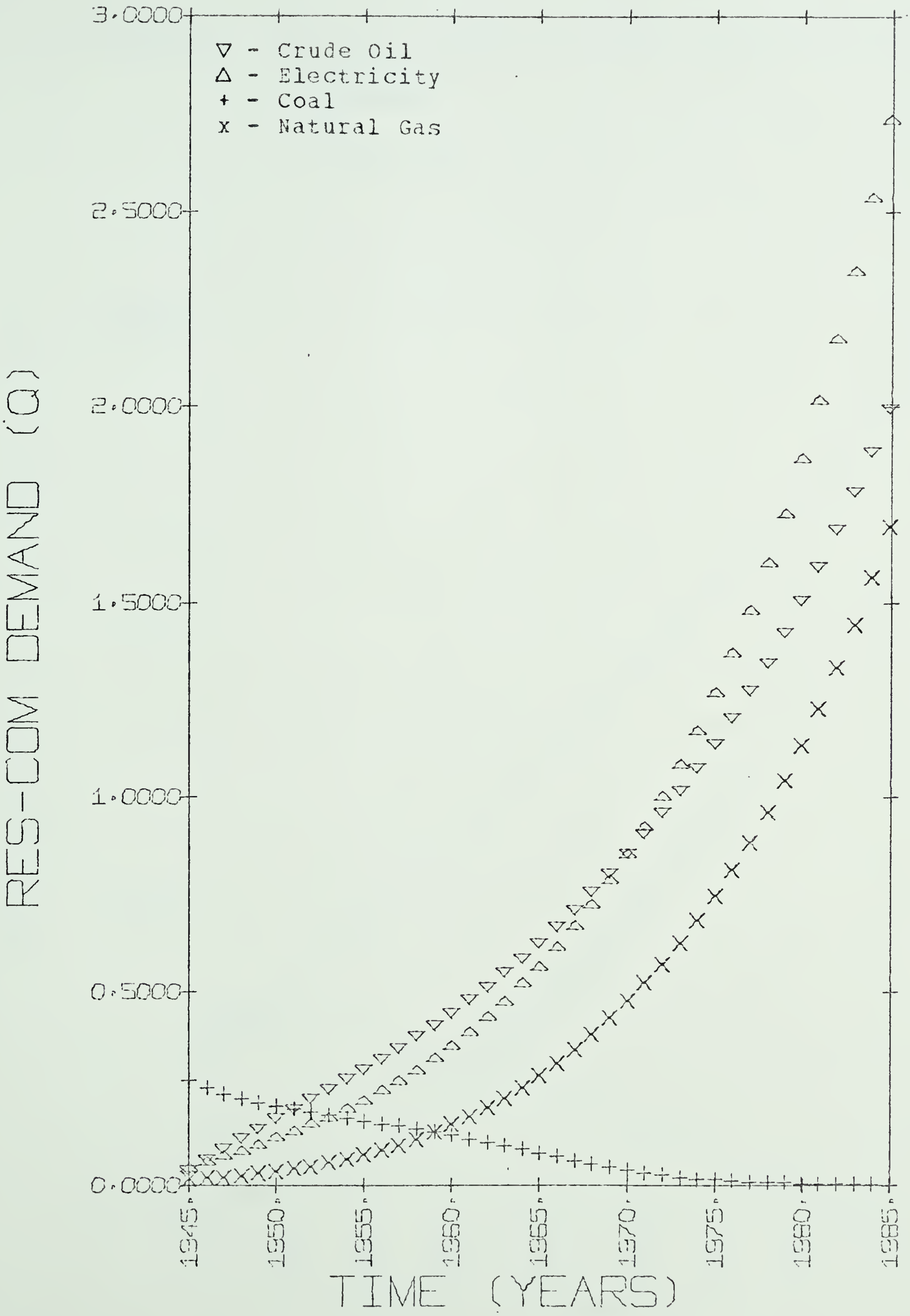

FIGURE IV.31 - RESIDENTIAL-COMMERCIAL DEMAND, CASE II 1945-85.

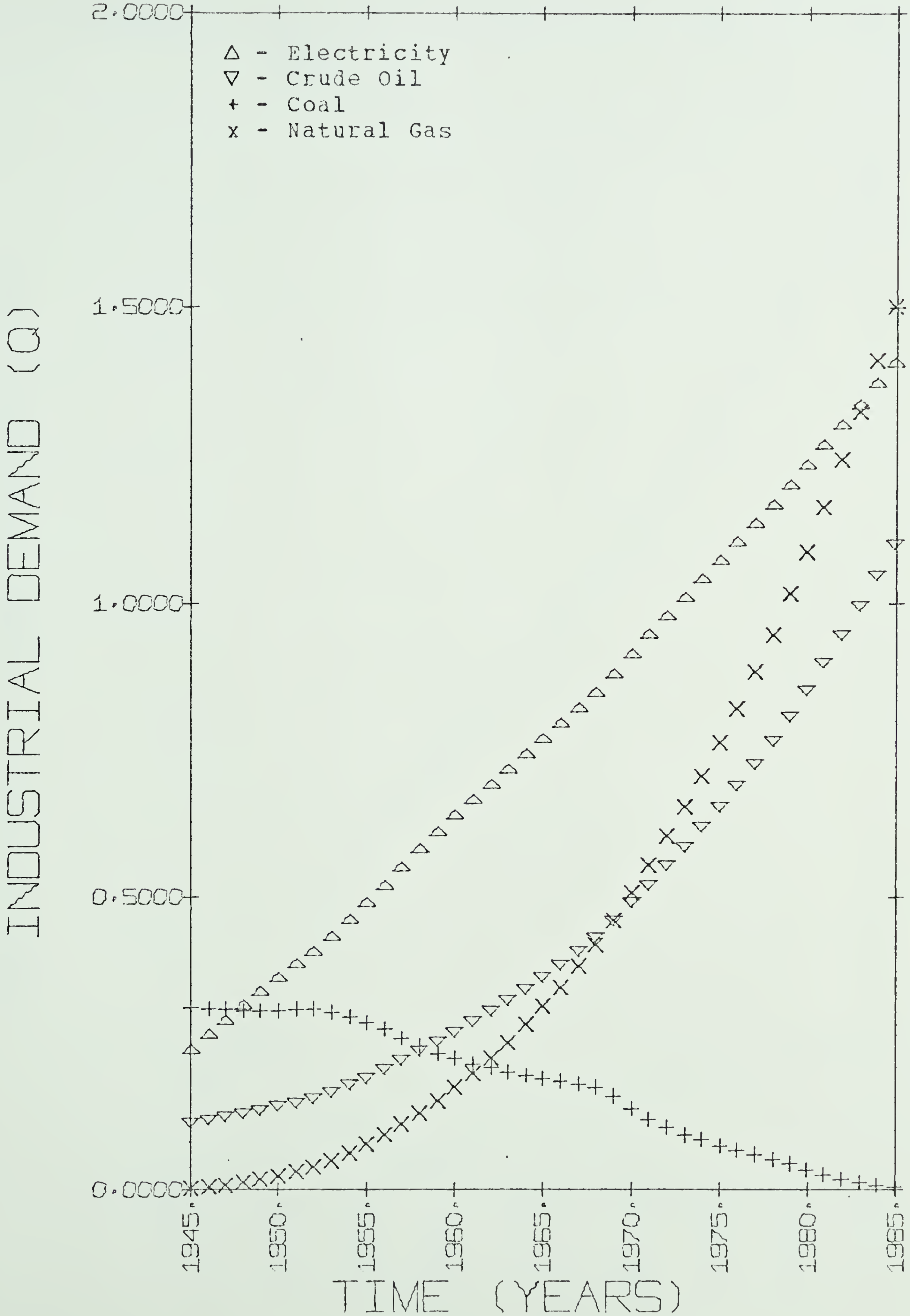

FIGURE IV.32 - INDUSTRIAL DEMAND, CASE II 1945-85.

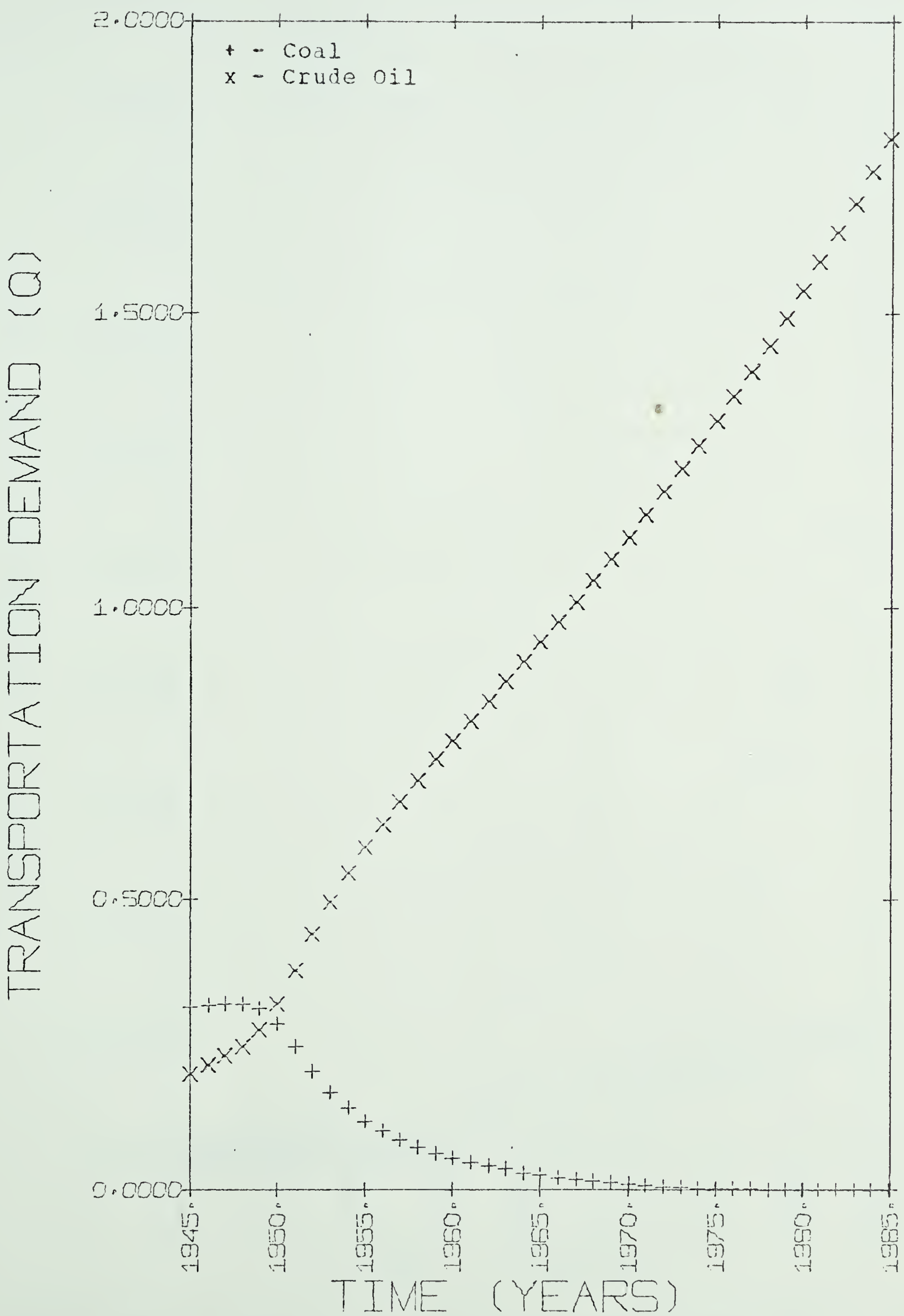

FIGURE IV.33 - TRANSPORTATION DEMAND, CASE II 1945-85.

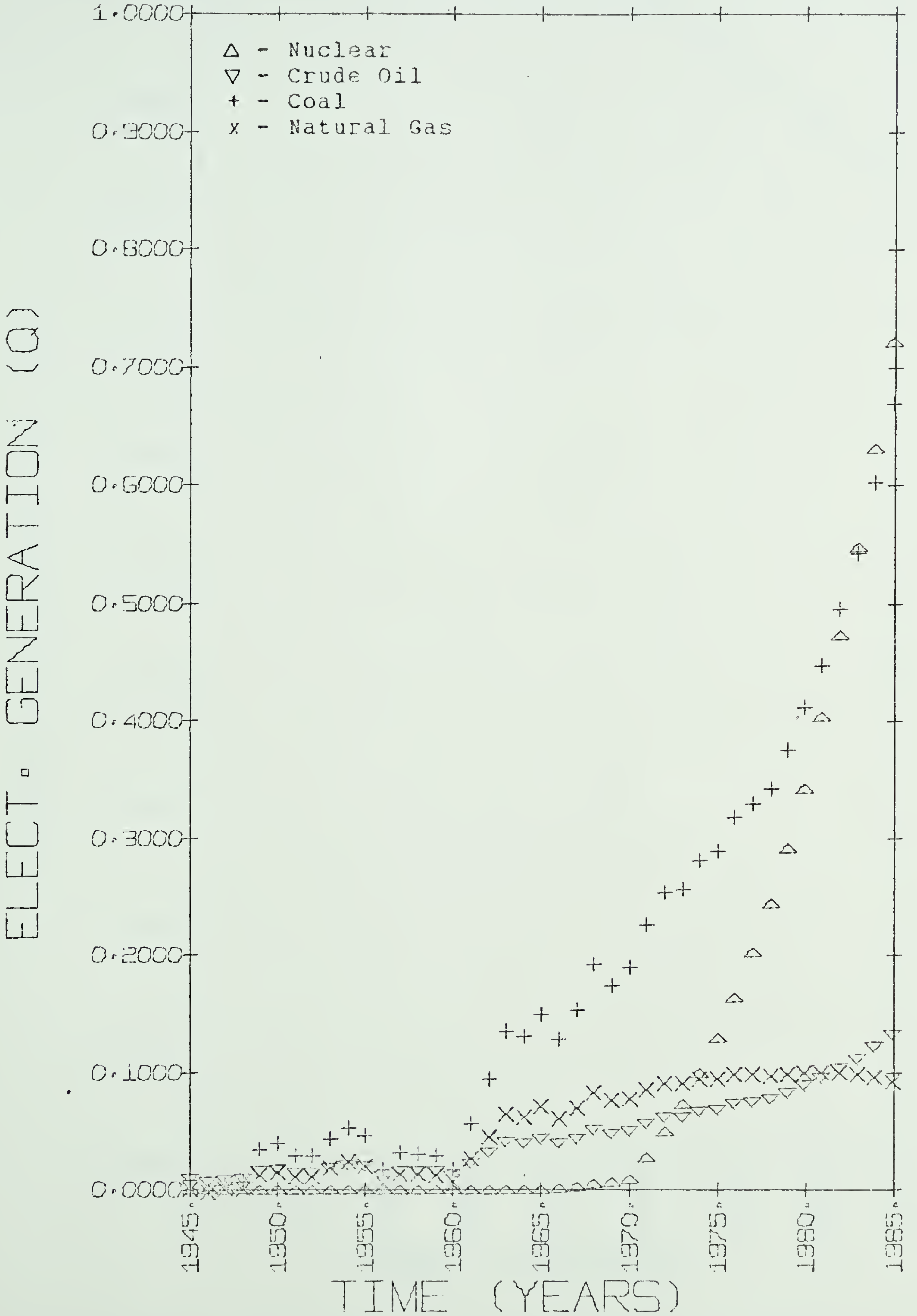

FIGURE IV.34 - ELECTRICITY GENERATED FROM PRIMARY FUEL FORMS, CASE II 1945-85.

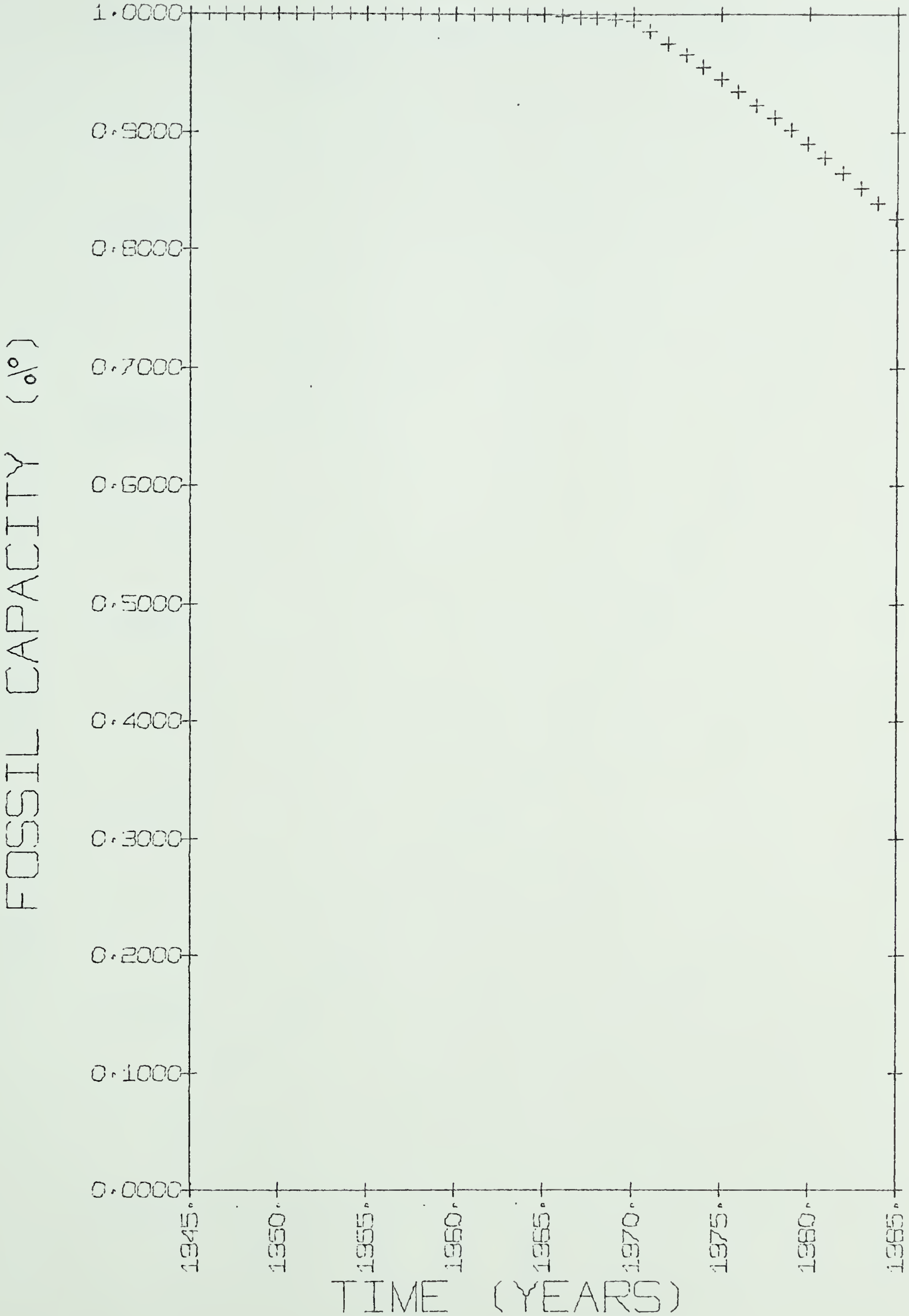

FIGURE IV.35 - PERCENTAGE OF TOTAL ELECTRICAL GENERATING CAPACITY WHICH IS DEPENDENT ON NON-NUCLEAR FUEL, CASE II 1945-85.

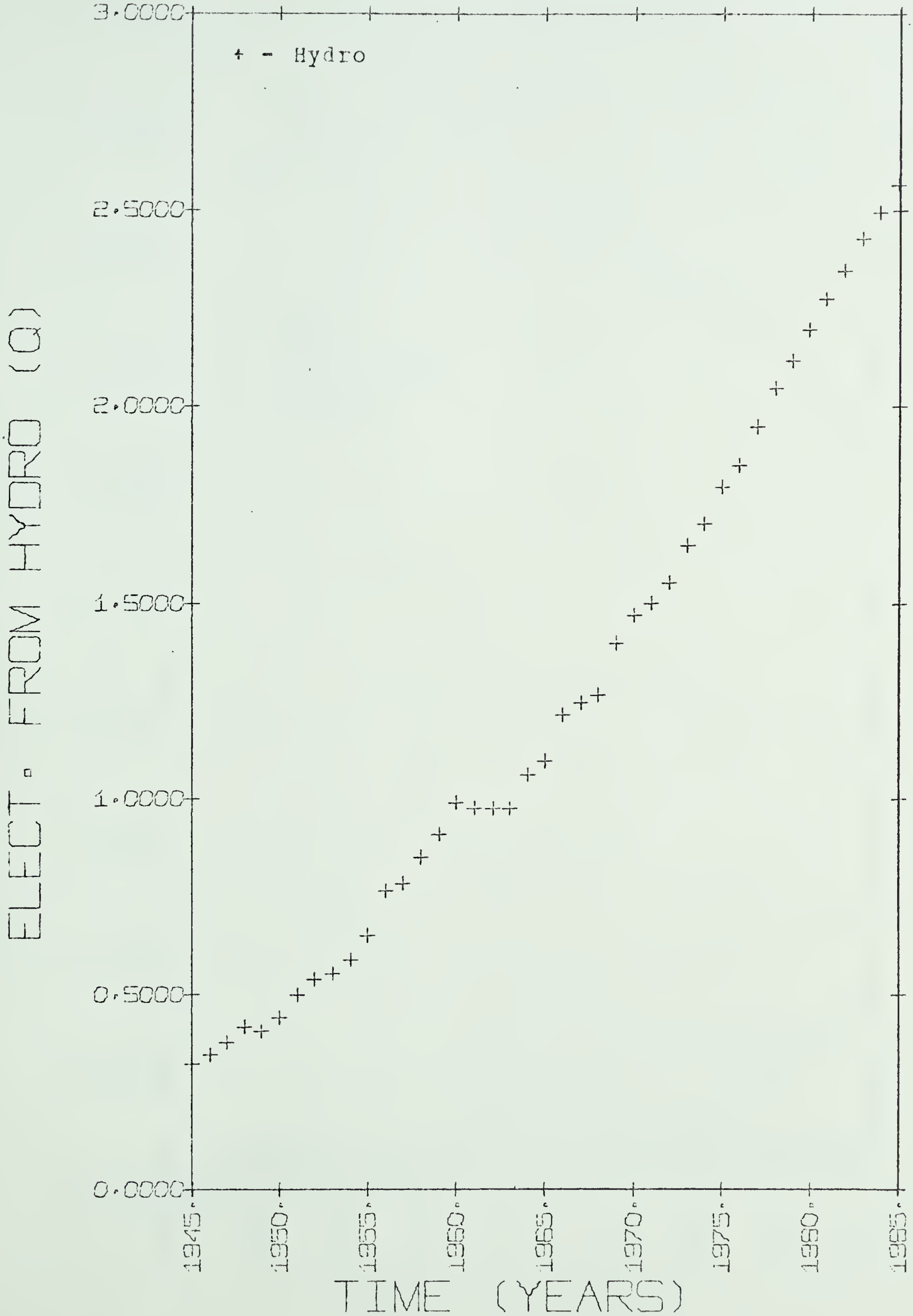

FIGURE IV.36 - ELECTRICITY GENERATED FROM HYDRO, CASE II 1945-85.

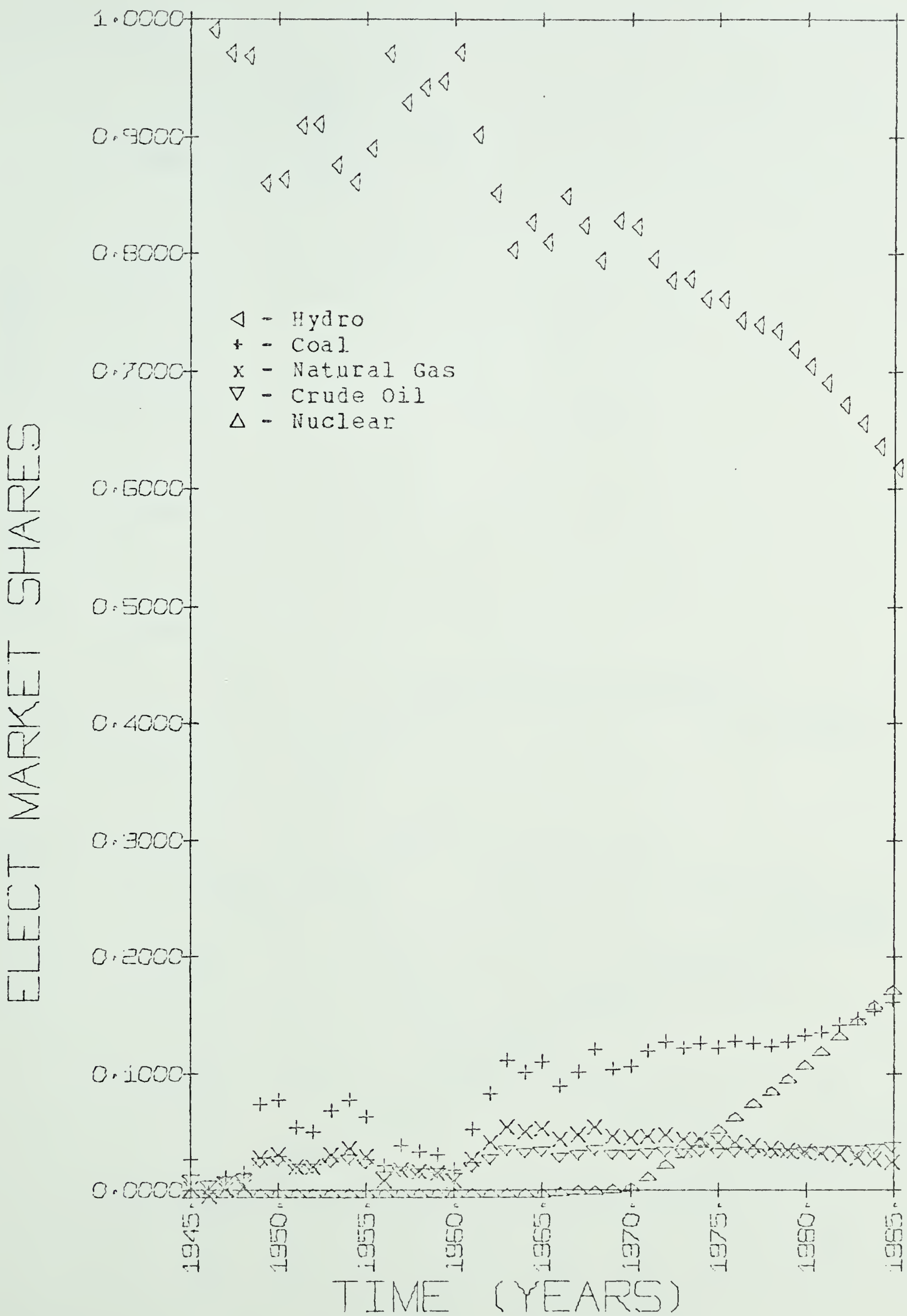

FIGURE IV.37 - PRIMARY FUEL MARKET SHARES IN THE ELECTRICITY GENERATING SECTOR, CASE II 1945-85.

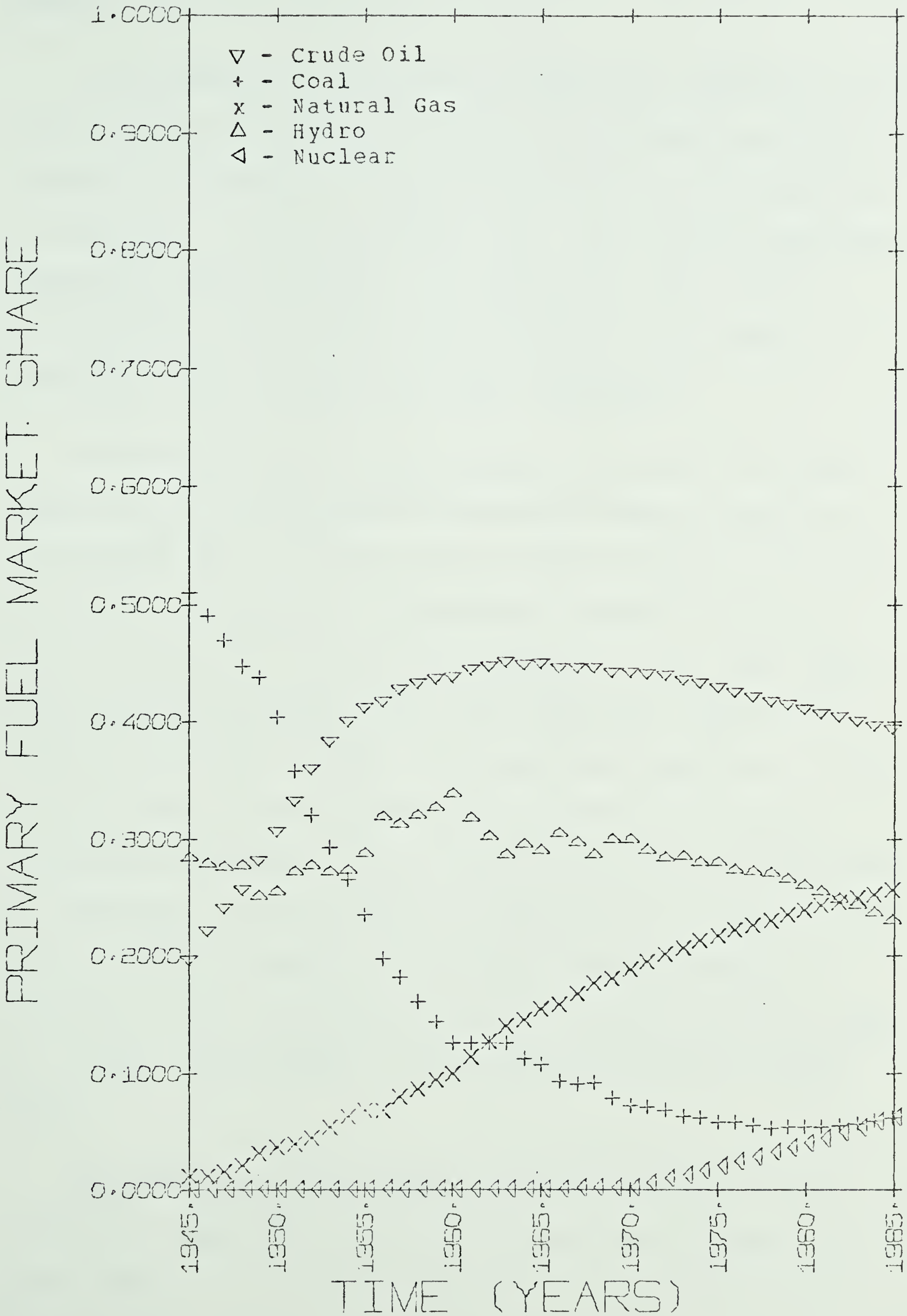

FIGURE IV.38 - PRIMARY FUEL MARKET SHARES FOR TOTAL CANADIAN ENERGY CONSUMPTION, CASE II 1945-85.

CASE 3

The effects of time-varying commitment liberation rates for consumers first became a point of interest during the parameter estimation of the equations for the distribution multipliers. It was discovered that time varying commitment liberation rates improved the explanatory power of the distribution multipliers, particularily in the case of industrial and transportation coal consumers.

Hence, this case study examines the effect of future increases in the commitment liberation rates of crude oil and natural gas consumers. Since natural gas and crude oil were first introduced as significant sources of energy in Canada in the mid 1940's, the consumers of the 'new' fuels have naturally possessed very low commitment liberation rates in the past. However, the conversion equipment of the initial crude oil and natural gas consumers is recently requiring replacement for the first time. This is manifested by increases in the commitment liberation rate (market entry rate) of these consumers. In addition, we can expect increases in the commitment liberation rates of oil and gas as a result of increases in the relative prices of these fuels.

Therefore, the hypothesized future scenarios of the commitment liberation rates for oil and gas consumers are given below.

1. Commitment Liberation rates[1]

- for the residential-commercial sector and the industrial sector, the commitment liberation rate for natural gas consumers is projected to increase from 10% per year in 1975 to 20% per year in 1985 while the commitment liberation rate for crude oil consumers is projected to increase from 10% per year in 1975 to 30% per year in 1985. The commitment liberation rates for fossil fuel consumers in the electricity generating sector are projected to be equal to those for natural gas consumers in the residential-commercial sector. All other commitment liberation rates are equal to those in effect in 1970 in the Base Case.

The other exogenous inputs assume the values that were assigned to them in Case 1.

The results of this projection are presented in Figures IV.45 to IV.53.

The consequence of increasing the consumer commitment liberation rates in any sector is to make that sector's consumption patterns more responsive to fuel price changes. Obviously, if the commitment liberation rates for all the consumers in a particular sector were 100% per year, then the total sector demand would respond instantaneously in each time period to the fluctuations in fuel prices and to other factors. As a result, the total sector fuel market

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[1] see Figures IV.32 to IV.35.

shares would be equal to the distribution multipliers without any time delay.

One historic example of the tremendous impact that a variable commitment liberation rate (regardless of what causes the variation) can produce is the sudden decline in coal consumption by the transportation sector after 1950.

Although the responses of the demand sectors in the projections of CASE 3 follow the expected trends, the full impact of the variable commitment liberation rates is once again not realized due to the strong influence of the variable TIME in the distribution multipliers.

It is interesting to note, however, that the results of this projection are similar, generally, to the results of forecasts made by the Department of Energy, Mines and Resources[1] and the Atomic Energy of Canada Limited (AECL)[2]. The projections of primary and secondary energy consumption by fuel and secondary energy consumption by sector produced by the 'Canadian Interfuel Substitution Model' are very close to the corresponding forecasts made by the Department of Energy, Mines and Resources. Unfortunately, further comparisons are made difficult because of the use of different KWH-BTU conversion constants. Atomic Energy of

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[1] Department of Energy, Mines and Resources An Energy Policy for Canada Ottawa, 1973 pgs. 73-75.
[2] E. C. W. Perryman "Canadian Power Reactor Program - Present and Future", Report #AECL-4265, Chalk River (1972) pg. 1.

Canada Limited forecasts that by 1985 Canada's nuclear power capacity will be approximately 14,000 MWe.. In CASE 3, the model projects that the nuclear power capacity of Canada will be around 13,000 MWe. in 1985.

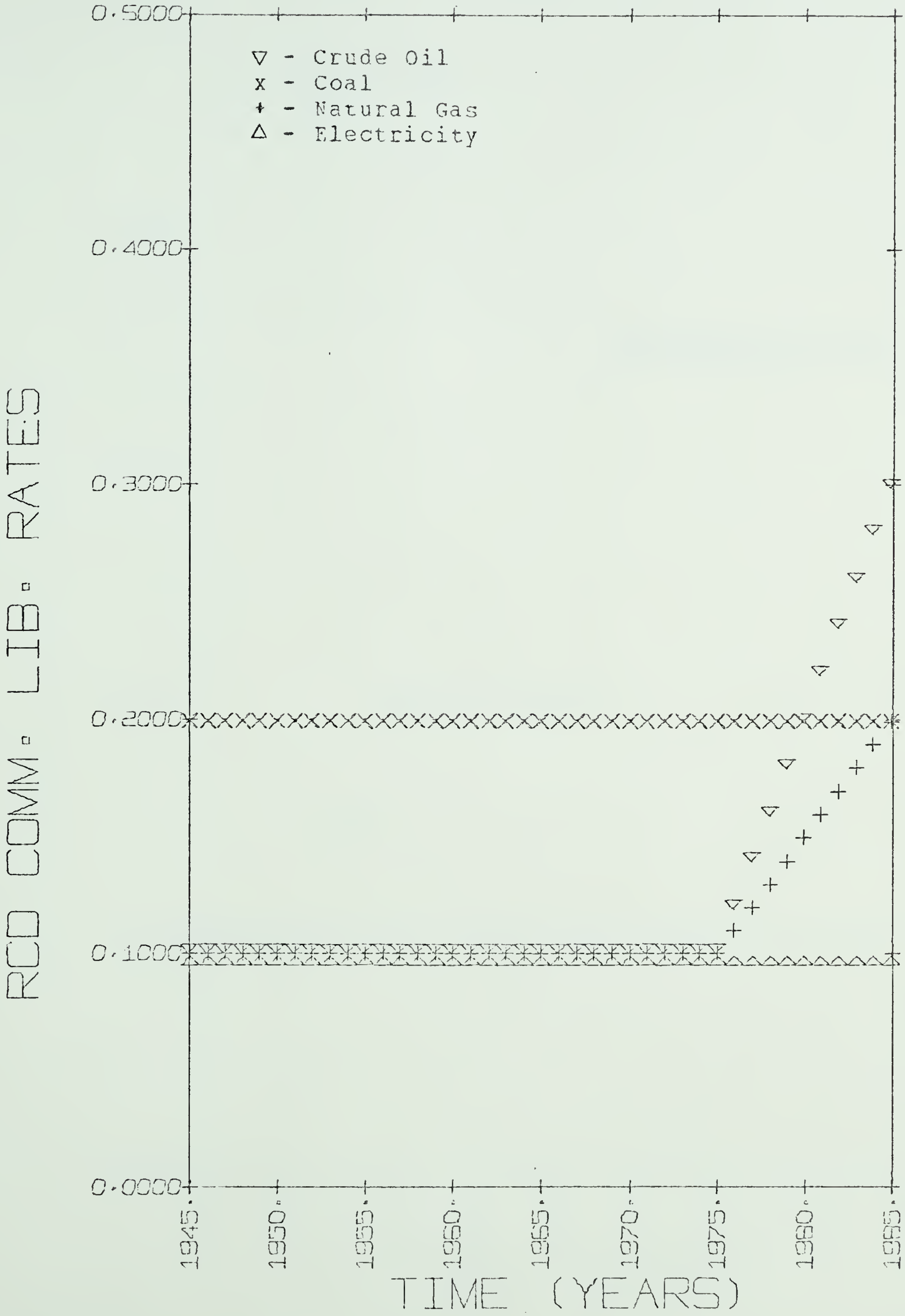

FIGURE IV.39 - CONSUMER COMMITMENT LIBERATION RATES FOR THE RESIDENTIAL-COMMERCIAL DEMAND SECTOR, CASE III 1945-85.

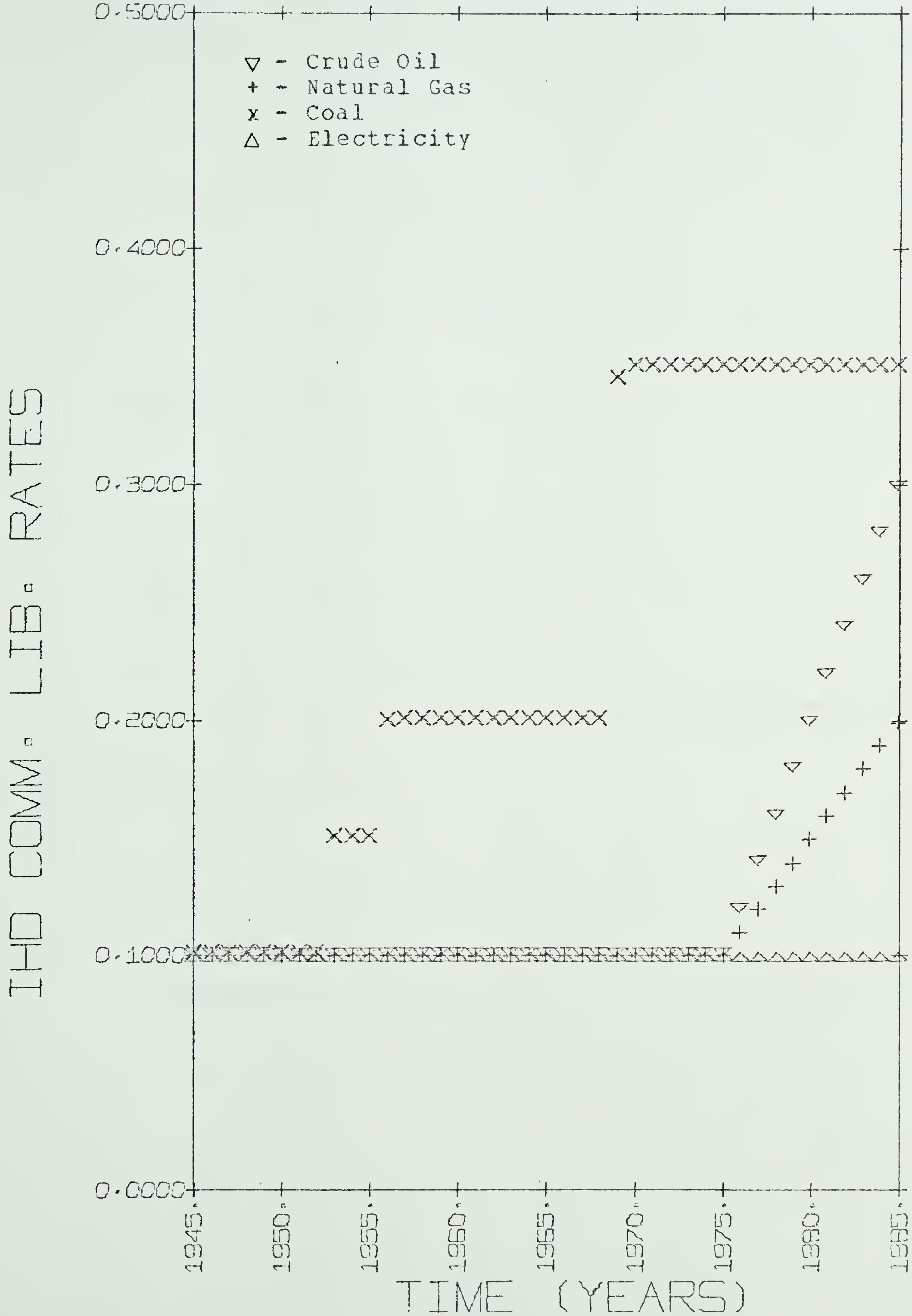

FIGURE IV.40 - CONSUMER COMMITMENT LIBERATION RATES FOR THE INDUSTRIAL DEMAND SECTOR, CASE III 1945-85.

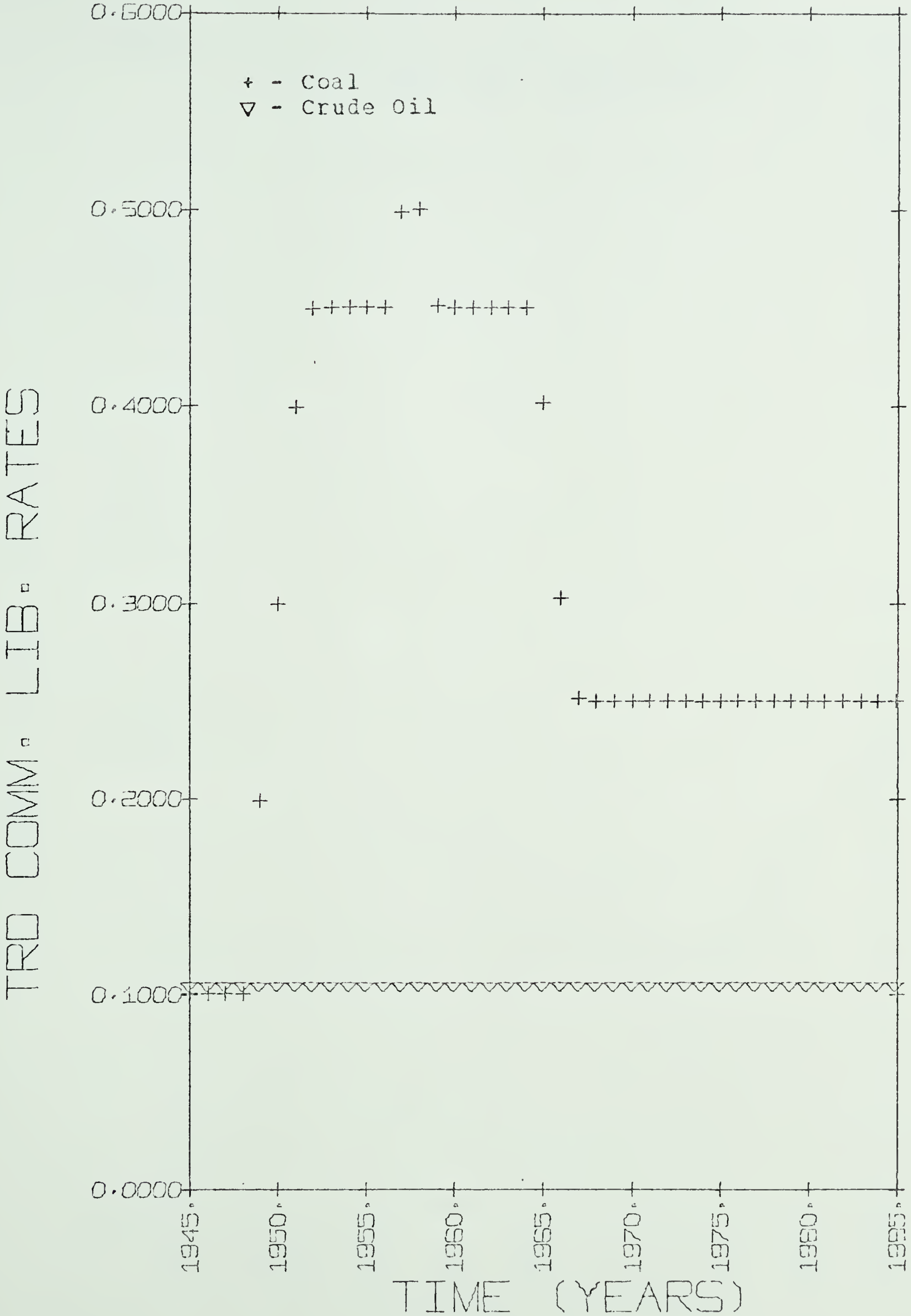

FIGURE IV.41 - CONSUMER COMMITMENT LIBERATION RATES FOR THE TRANSPORTATION DEMAND SECTOR, CASE III 1945-85.

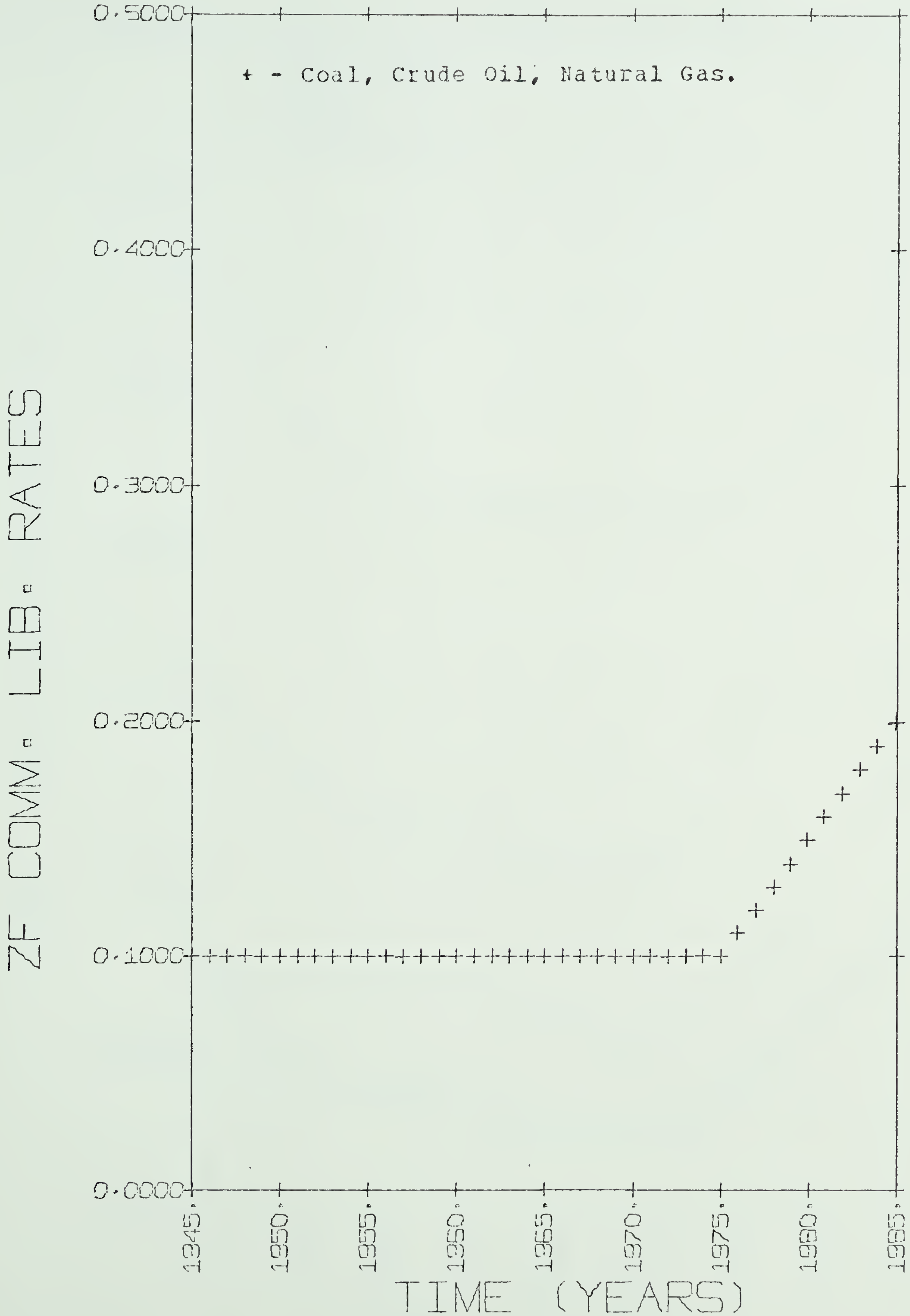

FIGURE IV.42 - PRODUCER COMMITMENT LIBERATION RATES FOR THE ELECTRICITY GENERATING SECTOR, CASE III 1945-85.

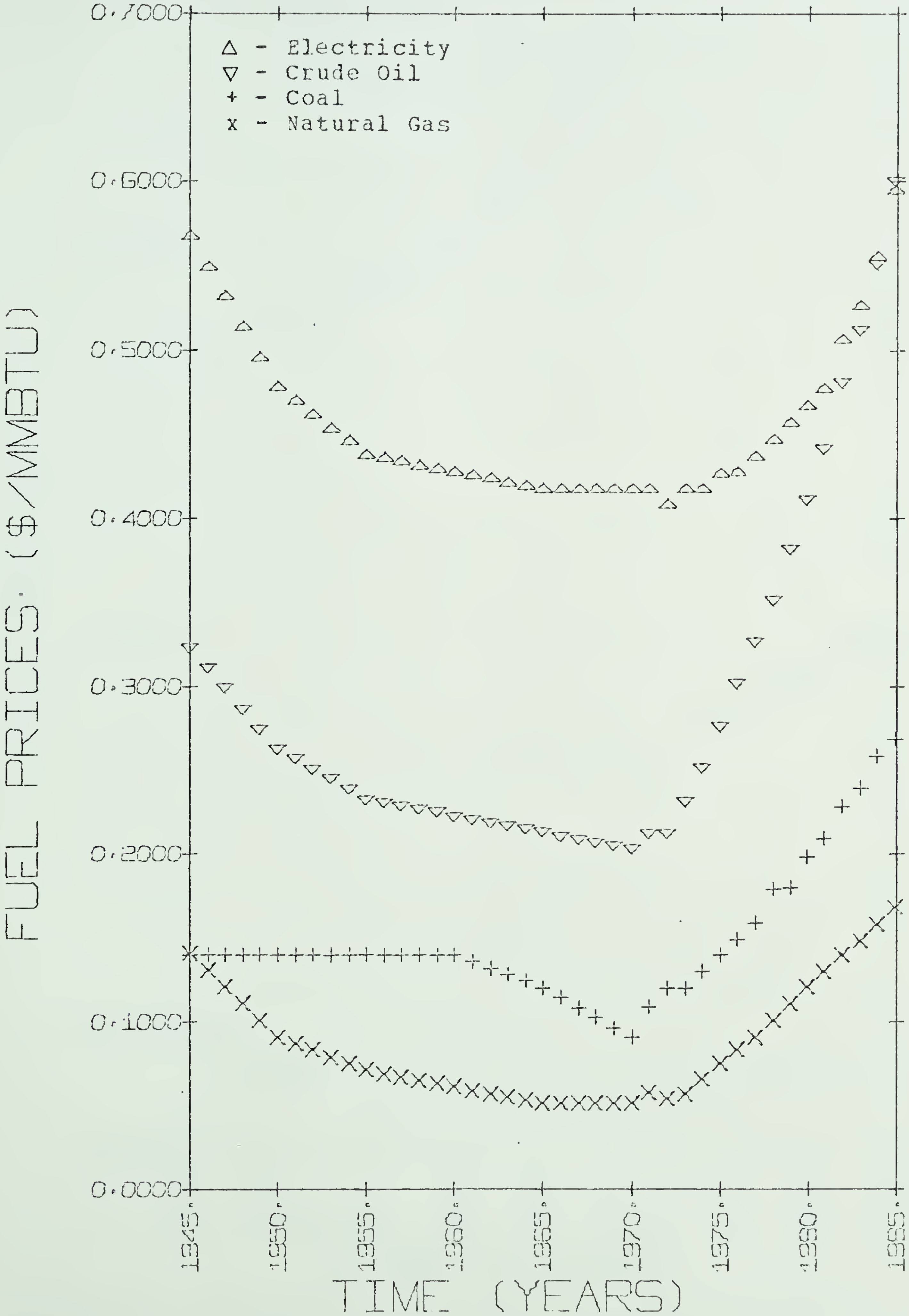

FIGURE IV.43 - FUEL PRICES, CASE III 1945-85.

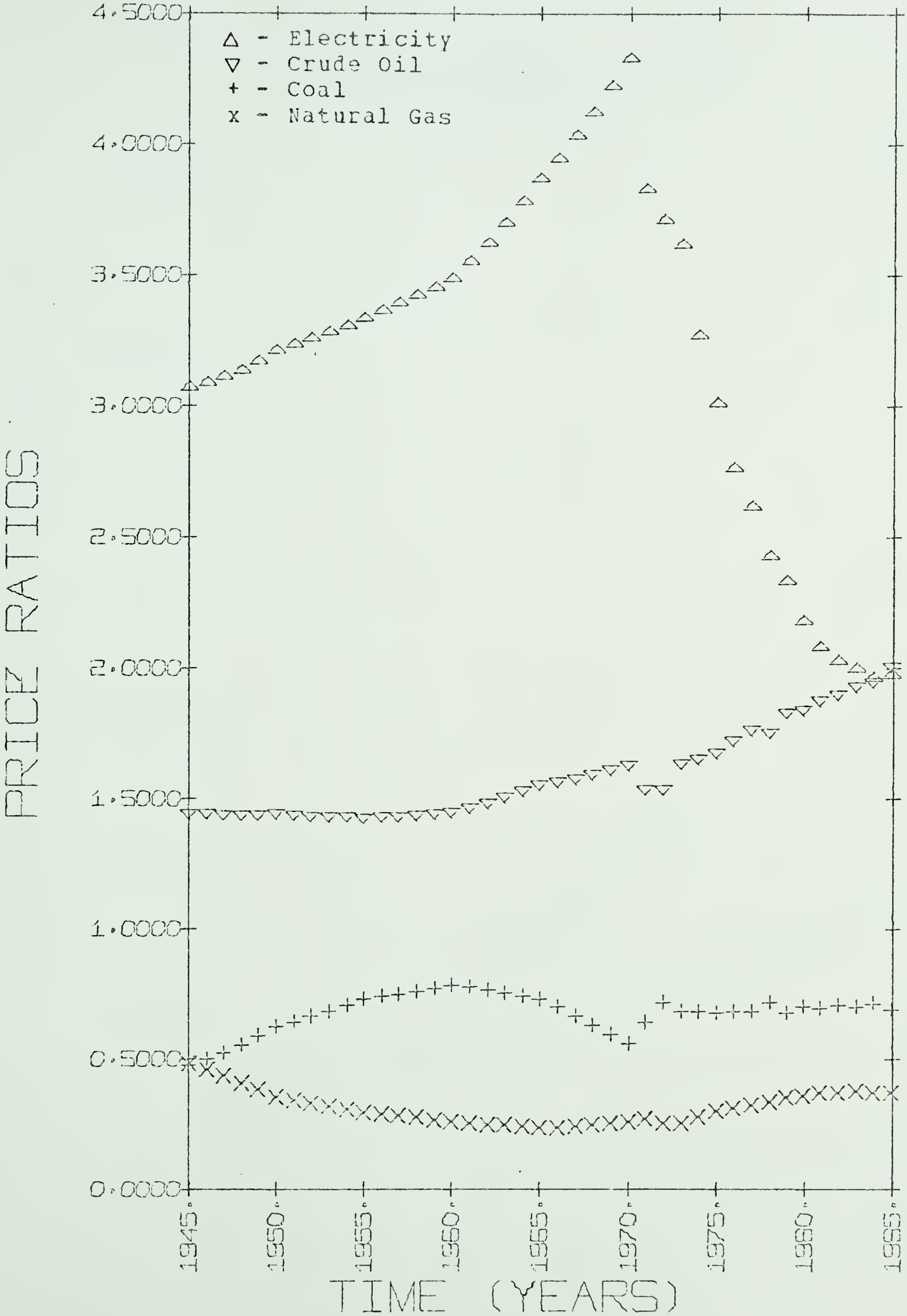

FIGURE IV.44 - RELATIVE PRICES OF THE FUEL FORMS, CASE III
1945-85.

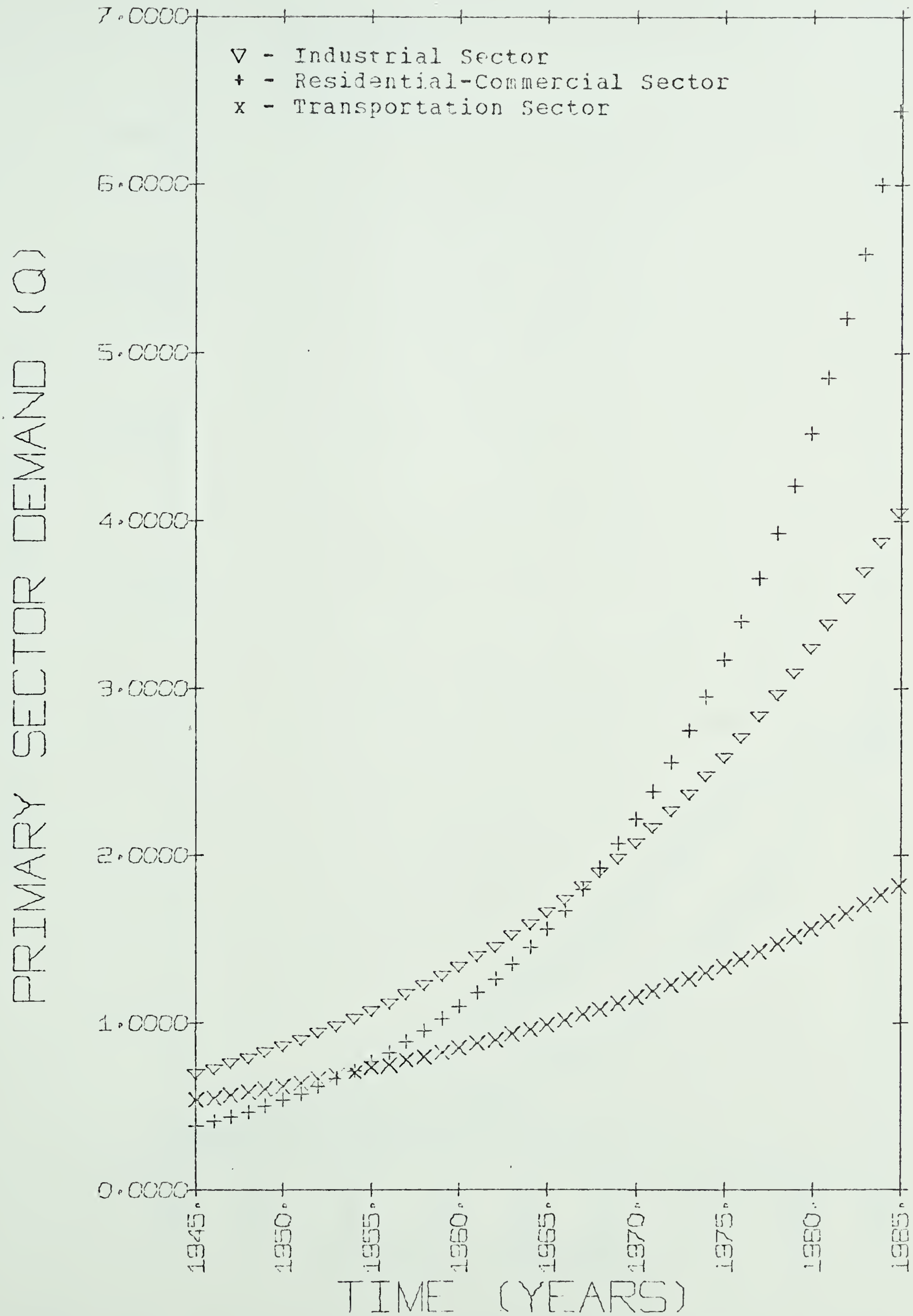

FIGURE IV.45 - ENERGY DEMAND BY THE PRIMARY CONSUMING SECTORS, CASE III 1945-85.

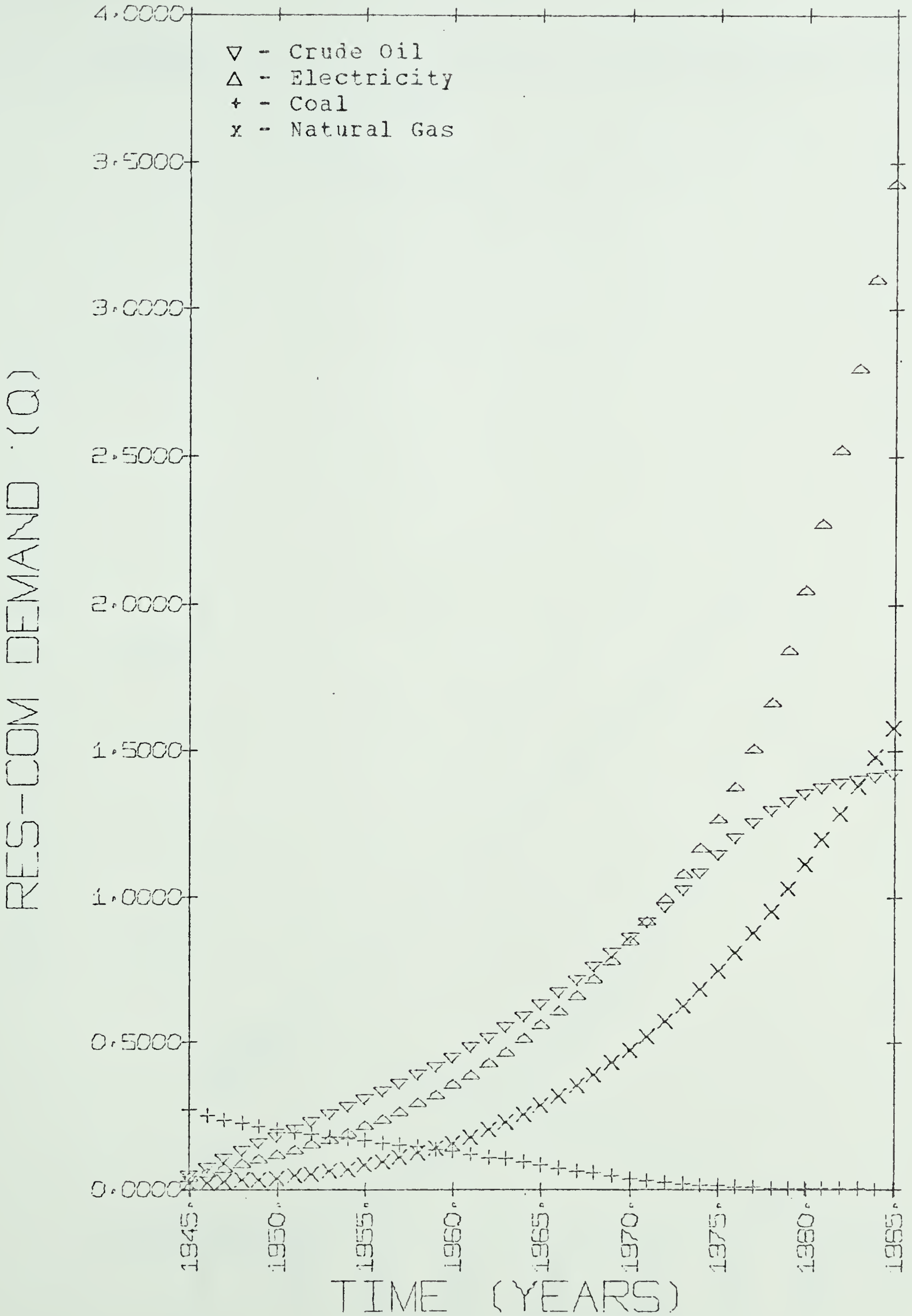

FIGURE IV.46 - RESIDENTIAL-COMMERCIAL DEMAND, CASE III 1945-85.

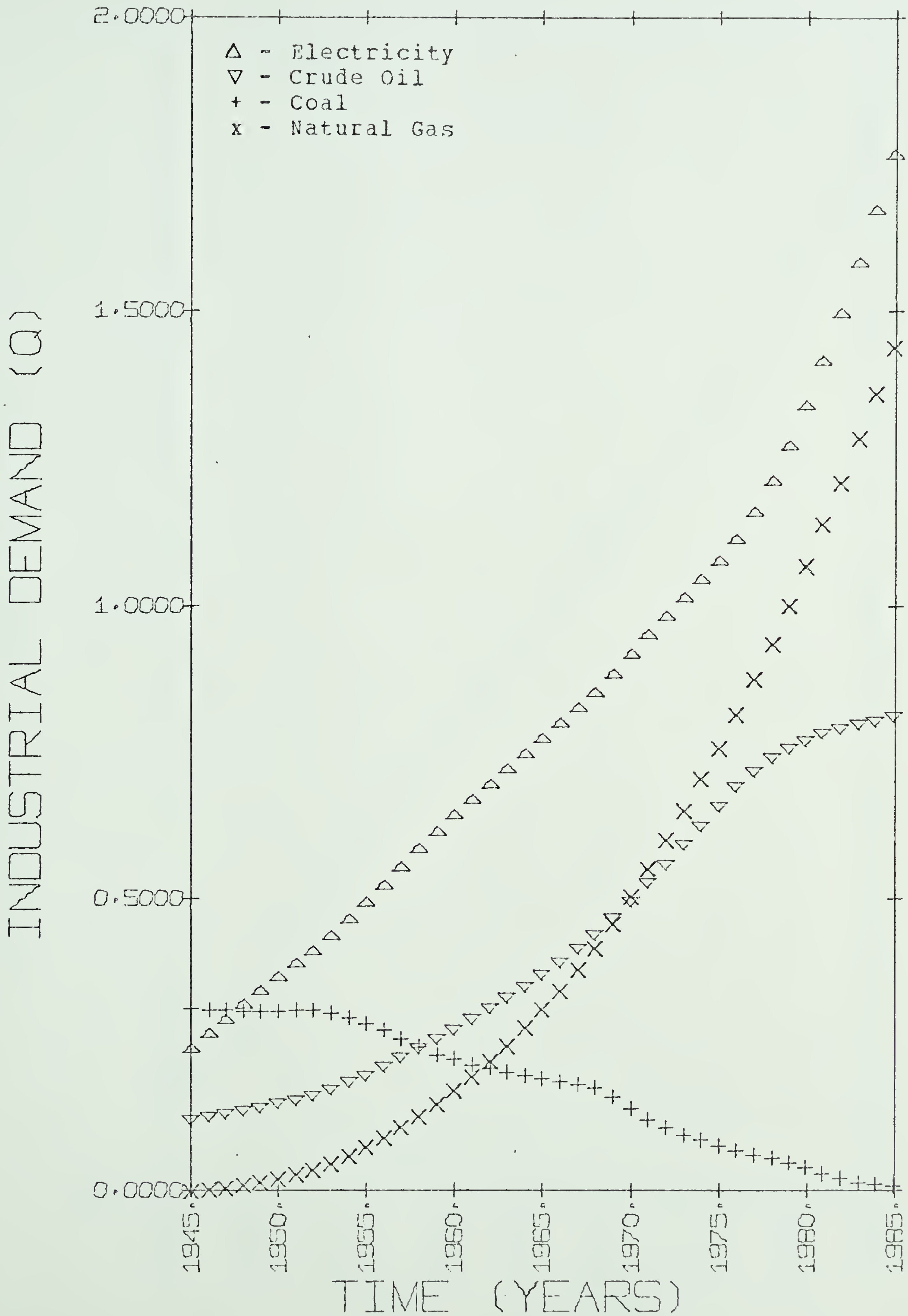

FIGURE IV.47 - INDUSTRIAL DEMAND, CASE III 1945-85.

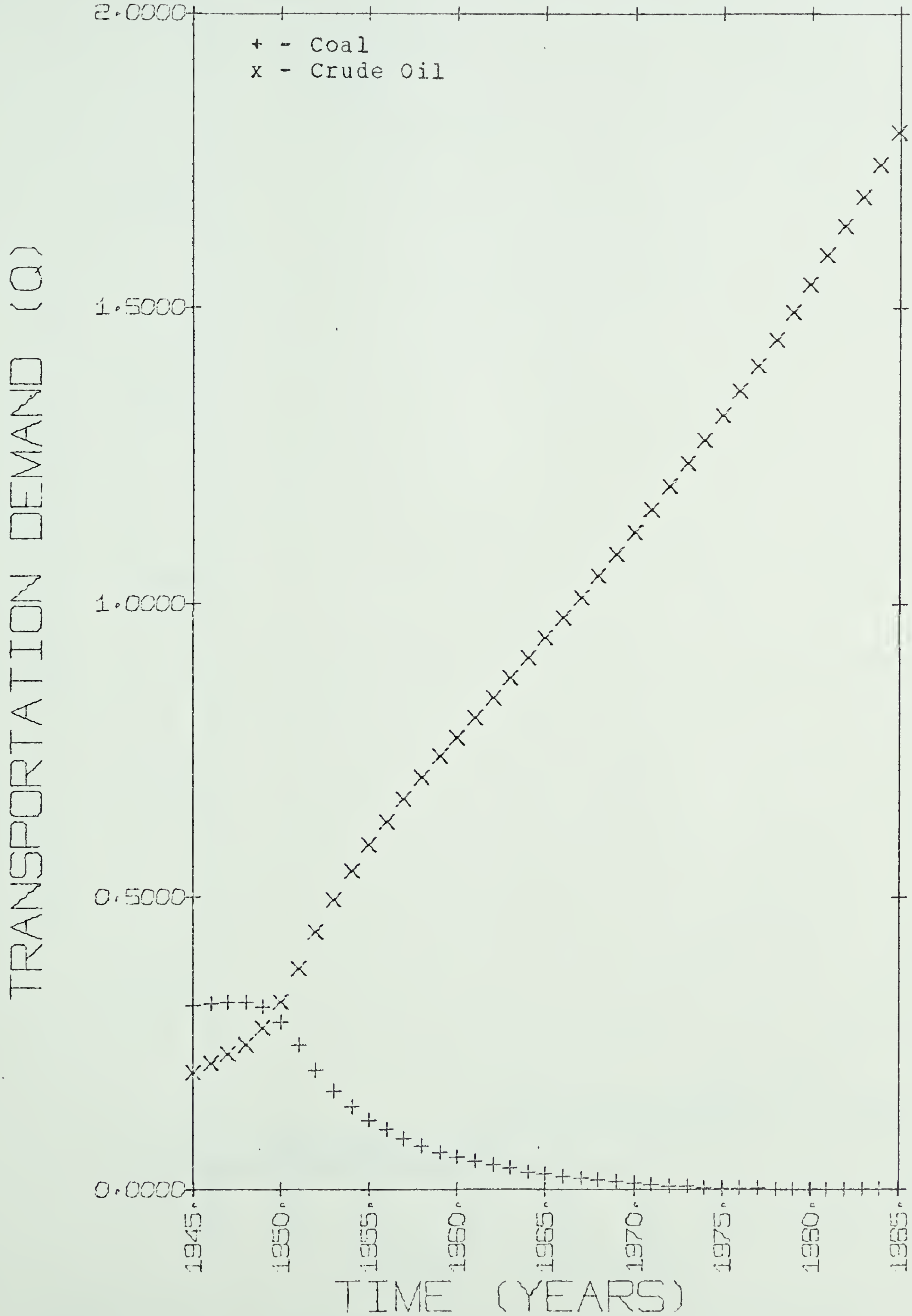

FIGURE IV.48 - TRANSPORTATION DEMAND, CASE III 1945-85.

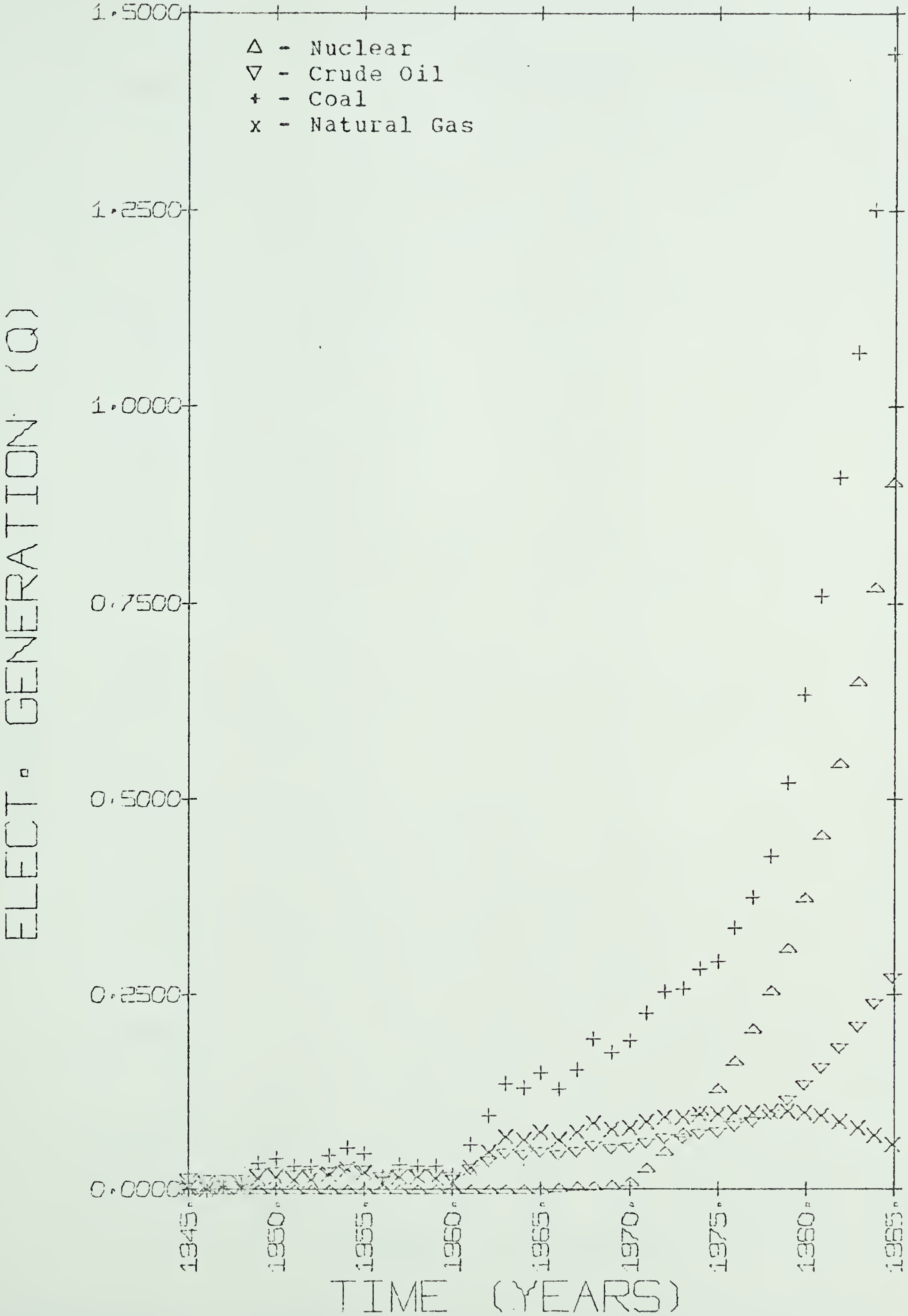

FIGURE IV.49 - ELECTRICITY GENERATED FROM PRIMARY FUEL FORMS, CASE III 1945-85.

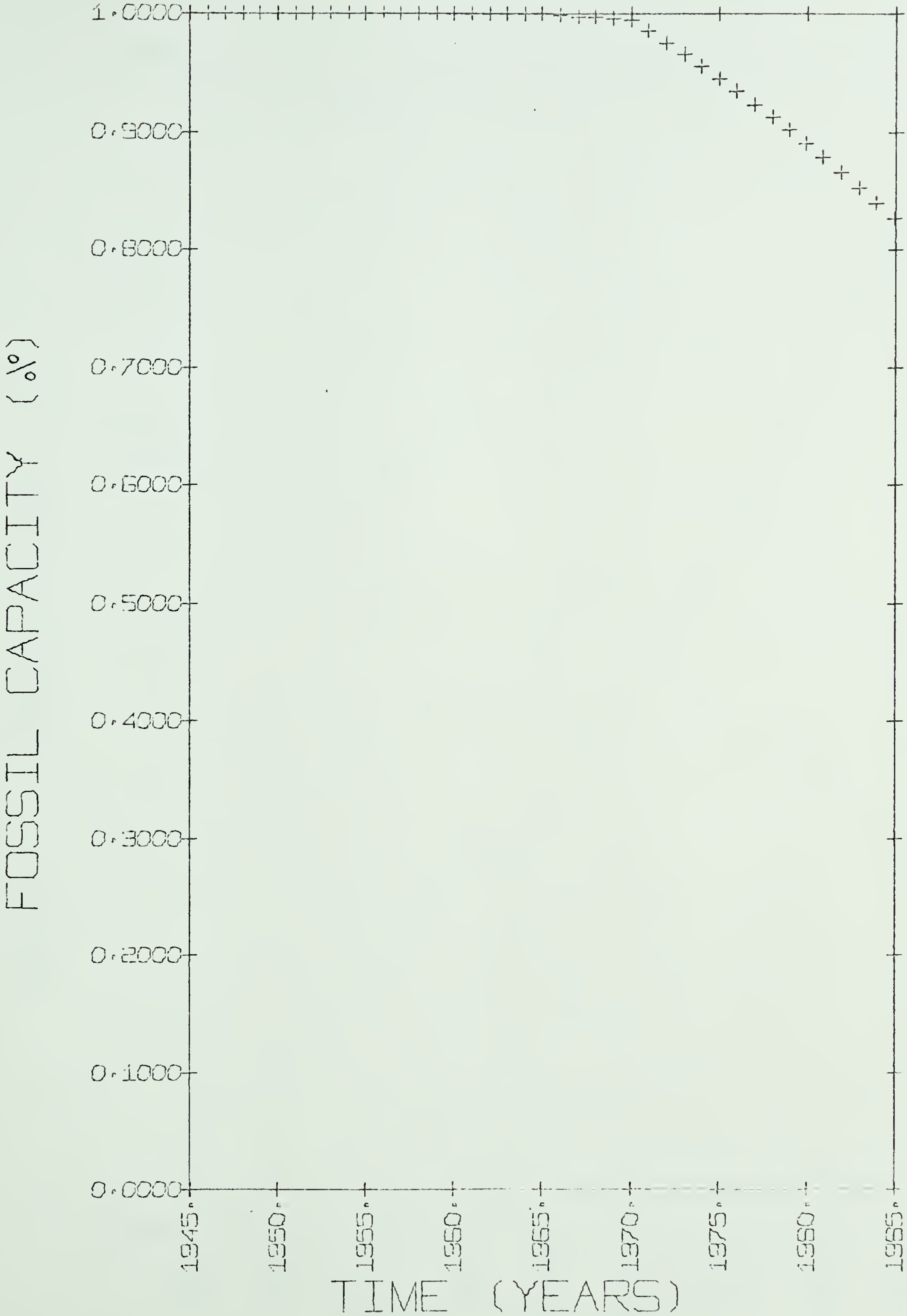

FIGURE IV.5? - PERCENTAGE OF TOTAL ELECTRICAL GENERATING CAPACITY WHICH IS DEPENDENT ON NON-NUCLEAR FUEL, CASE III 1945-85.

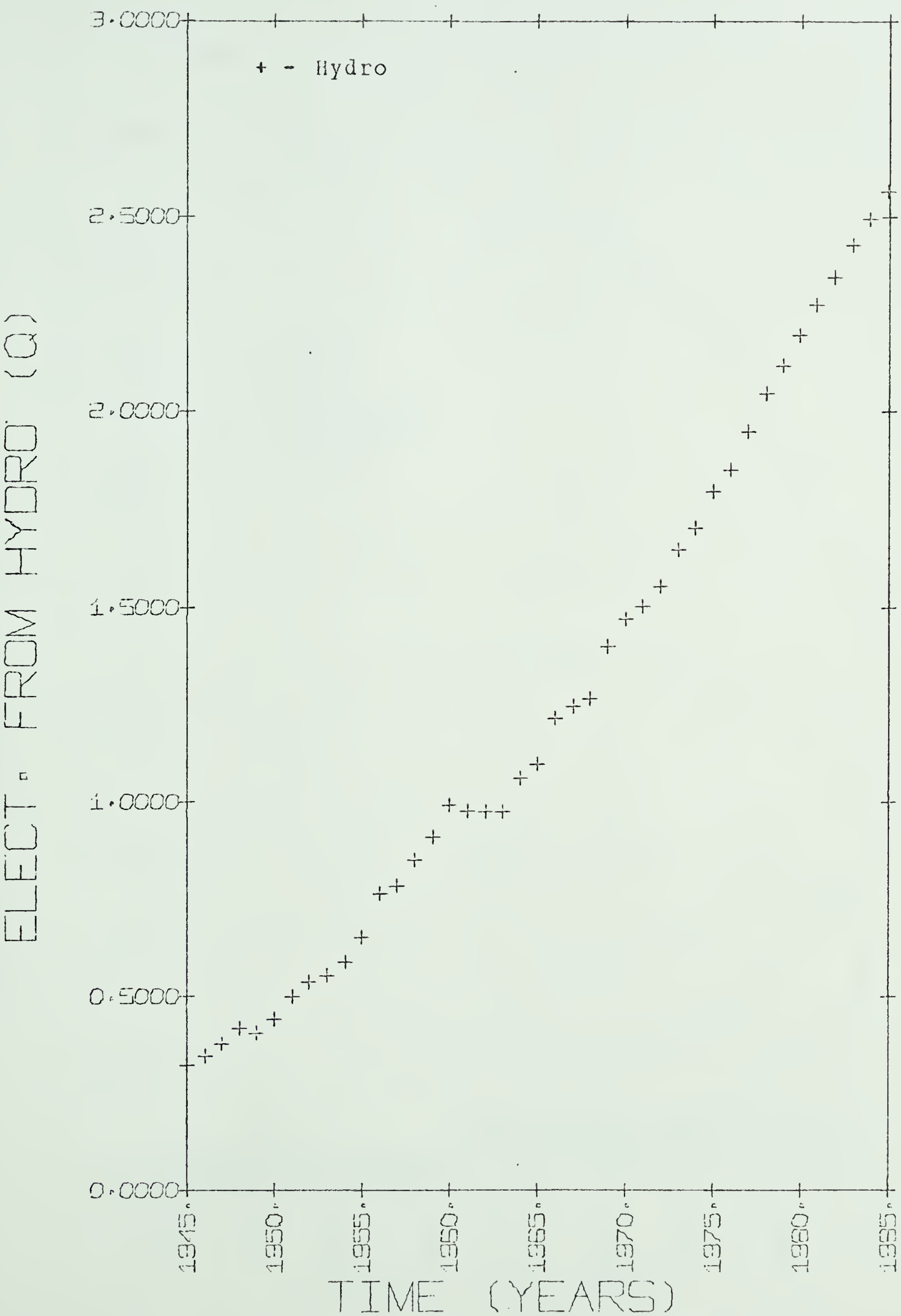

FIGURE IV.51 - ELECTRICITY GENERATED FROM HYDRO, CASE III 1945-85.

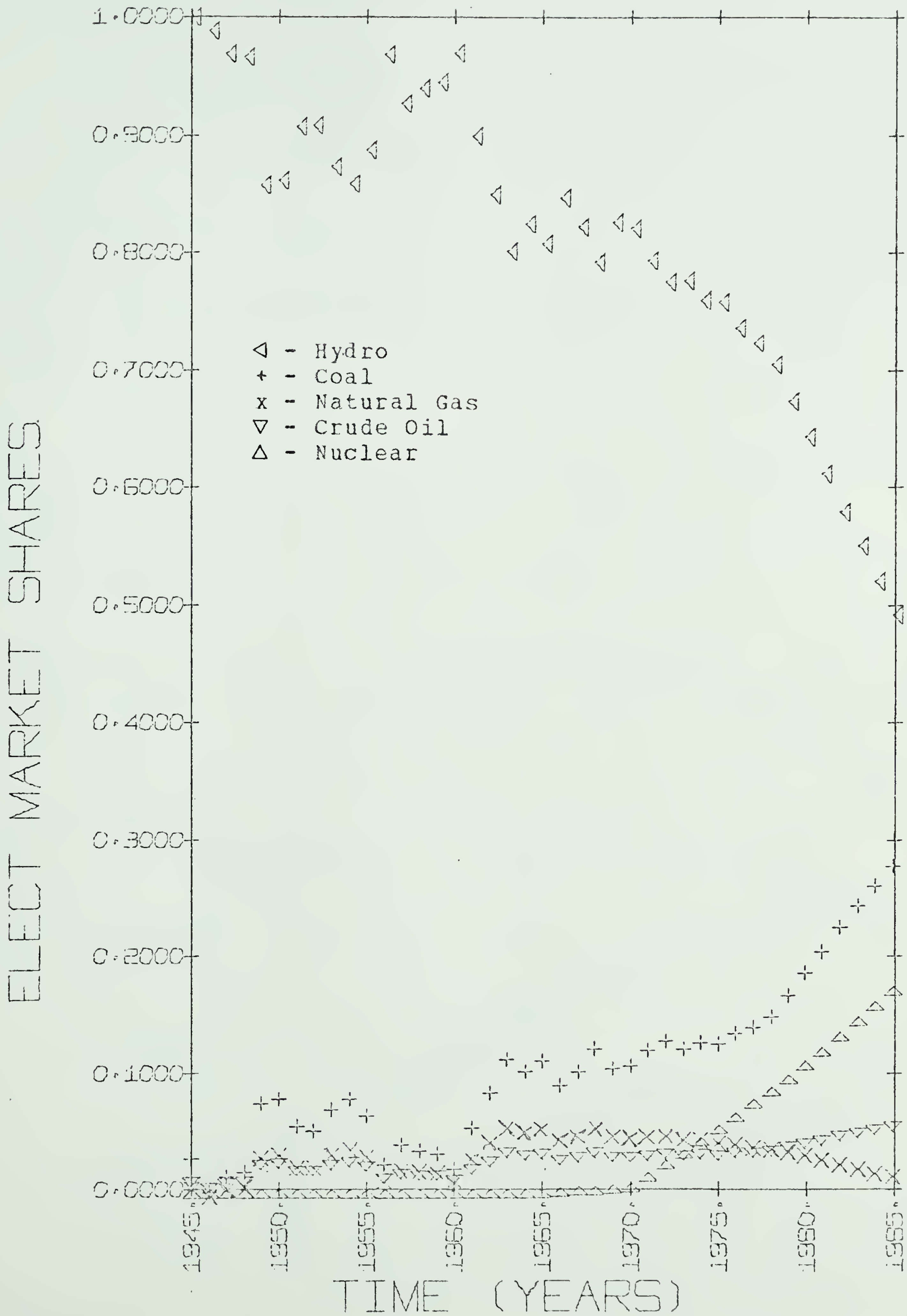

FIGURE IV.52 - PRIMARY FUEL MARKET SHARES IN THE ELECTRICITY GENERATING SECTOR, CASE III 1945-85.

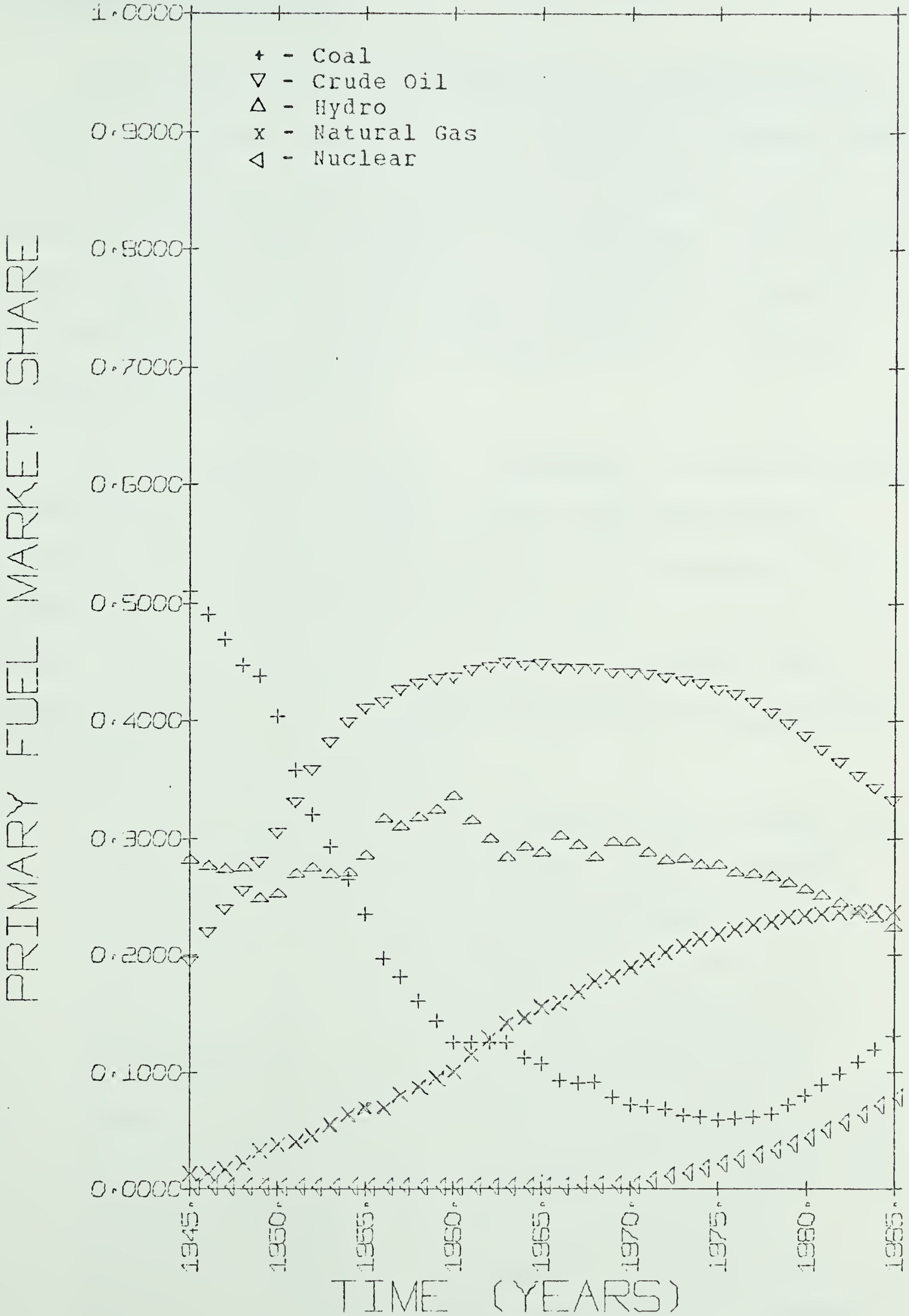

FIGURE IV.53 - PRIMARY FUEL MARKET SHARES FOR TOTAL CANADIAN ENERGY CONSUMPTION, CASE III 1945-85.

D. POLICY IMPLICATIONS

The broad interrelated nature of the energy industries and their crucial importance in an industrial economy compel the government of Canada to make energy related policy a top priority. The ultimate objective of government energy policy must be to ensure that the energy requirements of Canadians are satisfied on a smooth, continuous basis at a minimum social and economic cost.

For our purpose here it is desirable to consider energy policy in two facets - demand policy and supply policy. Despite their intimate relationship, the discussion will concentrate on energy demand policy. That is, what are the steps that may be taken by the Federal Government which directly affect energy consumers and satisfy the objectives of the overall energy policy?

1.) In 1970 more than 65% of Canada's total demand for primary energy forms was satisfied by non-renewable resources. This dependence on non-renewable energy sources will inevitably expand until the time when breeder reactors are technically, economically and environmentally feasible. As a consequence of the depletion of these non-renewable energy sources, there will be major interfuel transitions in the future. The Canadian government may assist in making these interfuel transitions less painful by making the following information readily available to consumers on a continuing basis:

- What are the short-term and long-term expected energy and conversion equipment costs?
- How secure are the suppliers of various energy forms?
- What are the physical depreciation rates of various conversion equipment? In other words, now long is a consumer committed to a particular fuel without an unexpected loss once he makes necessary capital investment in conversion equipment?
- What are the efficiency specifications and relative efficiencies of conversion equipment?
- In what instances and at what cost are capital substitutes for energy (i.e. insulation) available to consumers?

The existence of answers to such questions in an accessible form will aid consumers in formulating rational long-range stategies for energy utilization. This action is seen as 'preventive medicine' and would be particularily influential when aimed at consumers with free demand.

2.) The Economic Council of Canada, in its latest Annual Review (7), has recommended that the government allow Canadian energy prices to rise to the level of their international counterparts. Although higher natural gas and crude oil prices will achieve the objectives of conservation and, where possible, force the interfuel substitution process, such an

indiscriminate adjustment in prices may not be consistent with the goals of satisfying energy demand at minimum social and economic cost. That is, the same goals and objectives may be better achieved through the identification of four basic energy consuming groups. The base demand and the free demand energy consumers constitute two distinct groups of consumers while the efficient and inefficient energy consumers form two more distinct groups of consumers. It is suggested that significant changes in Canada's total energy consumption patterns can arise from policies which single out and influence the free demand consumers and the inefficient consumers. A government policy which produces large energy cost increases for efficient base demand consumers is not justified. Such a policy will not alter the consumption patterns of these consumers without drastic side effects. On the other hand, inefficient and free demand consumers will exhibit very elastic behavior with respect to energy costs and alterations in consumption patterns will be made with relative ease.

CHAPTER V

CONCLUSIONS AND FURTHER RESEARCH

In this study a preliminary model of the interfuel substitution process in Canada has been developed. The model, as it now exists, is referred to as a preliminary model because the developments, to date, simply identify the major factors or components in the interfuel substitution process without really analyzing these components in depth.

These critical factors in the interfuel substitution process are described below along with guidelines for further research.

COMMITMENT LIBERATION RATES - The broad definition that has been employed for the consumer commitment liberation rates makes further analysis of these rates very complex. In any event, the consumer commitment liberation rates have been clearly identified in this study as the major factors that are capable of altering consumer flexibility and responsiveness. It is expected that in addition to being dependent on the relative prices of energy fuels, these commitment liberation rates are also affected by technological considerations (i.e. inventions and innovations in conversion equipment) and tastes. However, further research of the consumer commitment liberation rates should probably proceed on a disaggregated, sector-by-sector

basis and even include some case studies.

DISTRIBUTION MULTIPLIERS AND RELATIVE FUEL PRICES - During the development of the distribution multipliers it became clear that fuel prices as well as some non-price factors entered into the consumer's decision process. A significant result of this study was the finding that relative fuel prices, rather that absolute fuel prices, represent the fuel price aspects in the decisions of free demand allocation. In terms of a nationally aggregated model, the role of fuel prices in the energy consumer decision process is not considered a major area for further research.

DISTRIBUTION MULTIPLIERS AND NON-PRICE FACTORS - Contrary to the assumptions made by Baughman (1), it has been found in this study that the behavior of the distribution multipliers is not adequately described by the fuel prices alone. Although the additional explanatory variables in this study were represented simply by a variable TIME, it is believed that this variable is a manifestation of other underlying factors. It is difficult to speculate on the fundamental determinants of these non-price factors. This is an important area for further research and it is expected that the results will be different for each distribution multiplier. Another area of interest, which was not covered in this study, relates to the time trends and interactions of the relative weightings of the price and non-price factors in the distribution multipliers.

UTILIZATION RATE - Khazzoom (11) has pointed out that consumers may employ variable utilization rates. For example, a consumer with replacement demand may decide, after entering the marketplace, not to satisfy this demand. He may prefer to leave his conversion equipment temporarily inactive. Unfortunately, this option does not exist in the present structure of the "Canadian Interfuel Substitution Model". However, this factor could easily be incorporated into the model structure if the determinants of variable utilization rates were fully understood.

PRICE ELASTICITY OF DISTRIBUTION MULTIPLIERS - The discovery that the price elasticities of the fuel demands vary inversely with the fuel market shares is not completely understood. To aid in understanding this phenomenon it would be helpful to find other examples where the price elasticities of commodity substitutes are dependent on their relative market shares.

Substantial credit must be given to the methodology of large-scale mathematical modeling for assisting in the qualitative and quantitative identification of the major factors in the interfuel substitution process and their interrelationships. In addition, the model facilitates continuing work within a uniform framework. Some natural extensions and recommendations for future investigations of the "Canadian Interfuel Substitution Model" are:

(i) Development of a price determining dynamic model .

(ii) Development of a dynamic supply model.

Both of (i) and (ii) above could be easily adopted from the work of Baughman (1).

(iii) Further research into the determinants of total and per capita sector demands.

(iv) Disaggregation of the "Canadian Interfuel Substitution Model" to include consideration of regional phenomenon in Canada.

(v) An important issue which has not been properly addressed in the past relates to the matter of BTU conversion constants. Since these conversion factors are dependent upon conversion equipment efficiency rates, they should be regularly reviewed and updated. This seems particularly true for the KWH-BTU conversion constants which now assume two distinct values, depending on the time period in question.

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APPENDIX A

DATA

This appendix contains a presentation and discussion of the data upon which the 'Canadian Interfuel Substitution Model' is based. Although the data were converted to the common equivilents of British Thermal Units (BTU's) in the model, only the data in its original units will be presented here. However, the conversion constants used to convert the data from its natural units to BTU's will be given.

The sequence in which the data base will be presented and discussed will proceed from the fuel price data to the sector-by-sector demand data for each fuel form and finally to the conversion constants.

FUEL PRICE DATA

The 'Canadian Interfuel Substitution Model' was constructed at a high level of aggregation. It was felt that the fuel prices most easily represented and corresponding to this level of aggregation would be the fuel prices that exist at the site of their respective production. That is, the prices of oil and gas would correspond to the 'well-head' prices and the price of coal would be the price paid for it at the mine site. Unfortunately, the data were not available to calculate the price of electricity in this same manner. As a result the price of electricity actually

represents the average price paid by consumers in Canada.

Tables A.1 to A.5 contain the data required to calculate the particular fuel prices. In order to translate the fuel prices into constant dollars the wholesale price index for non-metalic minerals (1935-39=100) was employed.

TABLE A.1

CCAL PRICES

YEAR	TOTAL CANADIAN PRODUCTION OF COAL (S.TONS x 10^6)	VALUE OF TOTAL PRODUCTION (DOLLARS x 10^6)	PRICE PER TON (CURRENT $)	PRICE PER TON (1935-39 $)
1945	16.507	67.588	4.094	3.517
1946	17.812	75.82	4.256	3.625
1947	15.869	77.475	4.882	3.781
1948	18.45	106.684	5.782	3.834
1949	19.12	110.915	5.800	3.664
1950	19.139	110.14	5.754	3.494
1951	18.587	109.039	5.866	3.454
1952	17.579	111.026	6.315	3.631
1953	15.901	102.722	6.460	3.651
1954	14.914	96.6	6.477	3.659
1955	14.819	93.579	6.314	3.604
1956	14.916	95.35	6.392	3.535
1957	12.96	90.252	6.963	3.678
1958	11.627	80.059	6.885	3.652
1959	10.514	74.089	7.046	3.778
1960	10.776	74.879	6.948	3.743
1961	10.336	70.181	6.789	3.666
1962	10.217	69.2	6.773	3.581
1963	10.452	72.052	6.893	3.637
1964	11.219	73.013	6.507	3.409
1965	11.5	76.295	6.634	3.462
1966	11.18	81.801	7.316	3.777
1967	11.141	56.5	5.071	2.545
1968	10.989	53.97	4.911	2.384
1969	10.672	50.578	4.739	2.256
1970	16.604	86.067	5.183	2.401
1971	18.432	121.727	6.604	2.925
1972	20.949	154.151	7.358	3.150
1973	21.960	176.979	8.059	3.156

TABLE A.2

NATURAL GAS PRICES

YEAR	TOTAL CANADIAN PRODUCTION OF NATURAL GAS (CU.FT. x 10^9)	VALUE OF TOTAL PRODUCTION (DOLLARS x 10^6)	PRICE PER 1,000 ft.^{3} (CURRENT $)	PRICE PER 1,000 ft.^{3} (1935-39 $)
1945	48.412	12.31	0.254	0.218
1946	47.9	12.165	0.253	0.216
1947	52.657	13.43	0.255	0.197
1948	58.603	15.633	0.266	0.176
1949	60.457	11.62	0.192	0.121
1950	67.822	6.433	0.094	0.057
1951	79.461	7.159	0.090	0.053
1952	88.686	9.518	0.107	0.061
1953	100.986	10.877	0.107	0.060
1954	120.735	12.482	0.103	0.058
1955	150.772	15.099	0.100	0.057
1956	169.153	16.85	0.099	0.055
1957	220.007	20.963	0.095	0.050
1958	337.804	32.058	0.094	0.050
1959	417.335	39.609	0.094	0.050
1960	522.972	52.197	0.099	0.053
1961	634.131	68.422	0.107	0.058
1962	894.672	108.641	0.121	0.064
1963	993.388	150.469	0.151	0.079
1964	1134.211	145.658	0.128	0.067
1965	1236.798	158.938	0.128	0.067
1966	1341.831	178.184	0.132	0.068
1967	1471.735	197.983	0.134	0.067
1968	1696.68	225.848	0.133	0.064
1969	1977.838	262.856	0.132	0.063
1970	2276.579	315.1	0.138	0.064
1971	2499.024	342.549	0.137	0.061
1972	2913.824	388.905	0.133	0.057
1973	3152.410	482.155	0.153	0.060

TABLE A.3

CRUDE OIL PRICES

YEAR	TOTAL CANADIAN PRODUCTION OF CRUDE OIL (BBLS. x 10^6)	VALUE OF TOTAL PRODUCTION (DOLLARS x 10^6)	PRICE PER BARREL (CURRENT $)	PRICE PER BARREL (1935-39 $)
1945	8.483	13.632	1.606	1.380
1946	7.586	14.989	1.975	1.683
1947	7.692	19.576	2.544	1.971
1948	11.896	37.419	3.145	2.085
1949	21.011	61.118	2.908	1.837
1950	28.646	84.6	2.953	1.793
1951	47.535	116.7	2.455	1.445
1952	61.161	143.	2.338	1.344
1953	80.78	200.6	2.483	1.403
1954	95.96	243.9	2.541	1.435
1955	129.26	305.6	2.364	1.349
1956	171.758	406.6	2.367	1.309
1957	181.127	453.6	2.504	1.322
1958	164.679	398.7	2.421	1.284
1959	183.601	422.1	2.299	1.232
1960	189.515	422.9	2.231	1.202
1961	220.816	487.6	2.208	1.192
1962	244.195	552.4	2.262	1.196
1963	258.162	615.2	2.382	1.257
1964	275.417	676.3	2.455	1.286
1965	292.322	719.	2.459	1.283
1966	320.549	789.3	2.462	1.271
1967	351.288	866.	2.465	1.237
1968	379.492	937.4	2.470	1.199
1969	410.99	1014.6	2.468	1.175
1970	461.18	1156.5	2.507	1.162
1971	492.739	1356.9	2.754	1.220
1972	562.31	1570.8	2.793	1.196
1973	649.868	2246.149	3.456	1.353

TABLE A.4

ELECTRICITY PRICES

YEAR	TOTAL CONSUMPTION OF ELECTRICITY IN CANADA (KWH. x 10^9)	TOTAL REVENUE FROM CUSTOMERS IN CANADA (DOLLARS x 10^9)	PRICE PER KWH. (CURRENT $)	PRICE PER KWH. (1935-39 $)
1945	34.7	0.215	0.006	0.005
1946	37.5	0.266	0.007	0.006
1947	41.	0.244	0.005	0.004
1948	45.1	0.257	0.005	0.003
1949	48.9	0.28	0.005	0.003
1950	53.459	0.324	0.006	0.003
1951	59.409	0.375	0.006	0.003
1952	64.023	0.415	0.006	0.003
1953	68.057	0.469	0.006	0.003
1954	71.94	0.506	0.007	0.003
1955	77.946	0.549	0.007	0.004
1956	83.59	0.597	0.007	0.003
1957	87.115	0.64	0.007	0.003
1958	93.685	0.692	0.007	0.003
1959	100.59	0.756	0.007	0.004
1960	109.302	0.805	0.007	0.003
1961	110.95	0.859	0.007	0.004
1962	116.135	0.908	0.007	0.004
1963	121.51	0.966	0.007	0.004
1964	133.949	0.963	0.007	0.003
1965	144.165	1.043	0.007	0.003
1966	156.956	1.131	0.007	0.003
1967	165.812	1.248	0.007	0.003
1968	176.841	1.386	0.007	0.003
1969	189.522	1.53	0.008	0.003
1970	202.337	1.716	0.008	0.003
1971	212.530	1.878	0.008	0.003
1972	231.557	2.065	0.008	0.003

TABLE A.5

WHOLESALE PRICE INDEX

YEAR	WHOLESALE PRICE INDEX FOR NON-MET. MINERALS (1935-39 = 1.0)
1945	1.164
1946	1.174
1947	1.291
1948	1.508
1949	1.583
1950	1.647
1951	1.698
1952	1.739
1953	1.769
1954	1.77
1955	1.752
1956	1.808
1957	1.893
1958	1.885
1959	1.865
1960	1.856
1961	1.852
1962	1.891
1963	1.895
1964	1.909
1965	1.916
1966	1.937
1967	1.992
1968	2.06
1969	2.1
1970	2.158
1971	2.258
1972	2.336
1973	2.554

The sector-by-sector demand statistics were difficult to obtain on a uniform basis because of the changing classifications in the data. As a result, many adjustments were required in the published data in order that it would conform to the data requirements of the model. These adjustments are outlined in the following discussions.

RESIDENTIAL-COMMERCIAL DEMAND DATA

The residential-commercial demand data for natural gas (1950-70) is equal to the sum of the residential demand data and the commercial demand data (28). Since the data for the 1945-50 time period were not available, the statistics were obtained by simple extrapolation of the 1950-70 statistics.

The demand data for electricity were obtained in a manner similar to that for natural gas. The residential-commercial demand data for electricity (1950-70) is the sum of the residential and commercial demand data (30). The data for 1945-50 were obtained by extrapolating the later data.

The data for residential-commercial coal demand were available (27) in the desired form. It was necessary, however, to extrapolate the 1949-70 data in order to obtain the statistics for the period 1945-49.

Complex problems were encountered with the data for the residential-commercial demand for crude oil. The data for the period 1945-62 were available (29) in the desired form. The data for 1965-67 were obtained by adding the separate

classifications of residential demand and commercial demand for coal. Then the values for the period 1963-64 were estimated by interpolation and the values for the period 1968-70 were estimated by extrapolation.

Table A.6 contains the data as it was used in the model.

INDUSTRIAL DEMAND DATA

There were greater problems encountered in obtaining the data for the industrial demand sector in its desired form than any other demand sector. This was particularly true for the coal and crude oil consumption data.

The industrial demand data for natural gas (28) and electricity (30) were available in the proper form in the original sources. It was necessary in both cases, however, to extrapolate the 1950-70 data in order to obtain statistics for the period 1945-50.

The industrial demand data (29) for crude oil for the period 1965-70 were acquired by subtracting the commercial demand for crude oil from the industrial-commercial demand for crude oil (29). The data for the period 1945-65 was then estimated extrapolating the 1965-70 data. The extrapolation was based, to a large extent, on the demand trends that existed in other sectors for crude oil. It was also based on the recognition that crude oil is a relatively 'new' fuel in Canada.

For the period 1963-70, the industrial demand for coal exists in the required form (27). Before this time period electricity generating demand for coal and the industrial demand for coal were classified in one category. Therefore, the electric utilities demand (27) for coal was subtracted from the 'industrial-electricity' (27) demand for coal to obtain the required statistics for the period 1949-62. The unavailable statistics for the period 1945-49 were obtained through extrapolation of the later data.

Table A.7 contains the industrial demand data as it was used in the model.

TRANSPORTATION DEMAND DATA

The transportation demand for coal existed almost solely within the railway sub-sector. Consequently, the railway demand data for coal (27) was collected.

The transportation demand for crude oil (29) was assumed to consist of the sum of the road, rail, marine, and aviation demands for this fuel. Unfortunately, these data were available in the required form only for the period 1965-70. The remainder of the statistics were obtained by extrapolation of the 1965-70 data.

Since the transportation demand for electricity and natural gas is negligible, no attempt was made to collect this data.

Table A.8 contains the transportation demand data as it was used in the model.

ELECTRICITY GENERATING DEMAND DATA

Electricity is usually considered to be generated by one of three broad categories: public utilities, private utilities and industrial establishments.

The only available data for the electricity generating demand sector, with the exception of hydro generation, was in the time period 1956-70. In the case of hydro generation, the data were available for the period 1949-70. As a result, estimates of the required data were obtained by extrapolation wherever necessary.

All the necessary data for this sector are available from one source (30) and are contained in Table A.9.

BTU CONVERSION CONSTANTS

The BTU conversion factors are functions which translate the energy quantities from their natural units to British Thermal Units (BTU's). With the exception of electricity, these functions have been represented by all researchers since 1945 as time invariant constants.

However, it has been recognized (10) that the efficiency of the electrical generation process has been steadily improving. As a result, two conversion constants

have arisen. They are based on the estimated conversion efficiencies of fossil fuel generating plants in the years 1955 and 1968. The 'Canadian Interfuel Substitution Model' utilizes a KWH-BTU conversion constant which lies between the two accepted values but is much closer to the 1968 estimate.

The constants, as used for the model, are listed in Table A.10 and the units correspond to the natural units of the data as collected.

TABLE A.6

RESIDENTIAL-COMMERCIAL DEMAND FOR ENERGY

YEAR	COAL (S.TONS x 10^6)	NATURAL GAS (CU.FT.x10^9)	CRUDE OIL (BBLS.x10^6)	ELECTRICITY (KWH.x10^9)
1945	10.5	18.	4.711	5.9
1946	10.31	22.	9.969	6.9
1947	10.1	26.	16.271	8.1
1948	9.8	31.	17.034	9.6
1949	9.259	36.	18.731	10.9
1950	9.06	40.004	24.669	12.685
1951	8.55	43.048	29.786	13.939
1952	7.144	43.328	34.863	16.005
1953	6.81	46.391	38.586	17.439
1954	6.554	56.864	46.808	19.618
1955	6.724	68.591	52.862	21.992
1956	6.33	77.937	61.277	24.16
1957	5.513	92.218	63.17	26.064
1958	5.225	112.94	68.108	27.865
1959	4.747	142.683	74.003	31.023
1960	4.219	161.255	77.375	33.029
1961	3.997	175.937	81.341	36.391
1962	3.617	198.594	87.942	39.816
1963	3.336	216.219	101.	43.916
1964	3.03	247.101	114.	48.702
1965	2.609	288.348	130.082	53.597
1966	2.187	310.983	132.603	61.218
1967	1.907	335.775	137.206	66.24
1968	1.533	359.248	141.7	71.932
1969	1.306	399.885	146.	78.985
1970	1.016	434.61	150.	87.499

TABLE A.7

INDUSTRIAL DEMAND FOR ENERGY

YEAR	COAL (S.TONSx10⁶)	NATURAL GAS (CU.FT.x10⁹)	CRUDE OIL (BBLS.x10⁶)	ELECTRICITY (KWH.x10⁹)
1945	11.9	3.	19.113	27.
1946	11.65	6.	18.780	28.5
1947	11.45	10.	15.805	30.2
1948	11.3	13.	18.679	32.
1949	11.421	15.	19.035	34.
1950	11.601	17.897	18.750	35.774
1951	11.714	21.869	21.368	39.691
1952	11.357	22.677	21.311	42.01
1953	11.986	24.284	21.239	44.184
1954	10.504	30.275	24.502	45.523
1955	11.322	48.699	28.877	48.634
1956	11.564	65.631	34.907	51.161
1957	10.581	75.385	35.307	52.583
1958	9.562	90.08	36.287	56.876
1959	8.782	139.567	40.464	59.736
1960	8.366	164.234	43.459	66.353
1961	7.958	194.803	48.487	64.354
1962	7.673	213.468	52.166	65.498
1963	7.715	235.379	58.015	66.579
1964	8.081	257.402	59.523	72.694
1965	8.279	284.669	62.534	77.28
1966	7.543	324.532	67.854	81.546
1967	7.381	359.331	74.654	84.539
1968	6.56	406.578	86.993	86.068
1969	5.442	444.829	86.917	94.435
1970	3.718	399.057	108.638	97.02

TABLE A.8

TRANSPORTATION DEMAND FOR ENERGY

YEAR	COAL (S.TONSx10⁶)	CRUDE OIL (BBLSx10⁶)
1945	12.084	38.226
1946	11.632	37.560
1947	12.33	39.513
1948	12.422	45.365
1949	12.855	49.491
1950	10.953	56.251
1951	10.712	70.145
1952	9.52	76.801
1953	8.002	83.564
1954	6.33	91.579
1955	5.852	103.957
1956	5.324	127.992
1957	3.109	134.855
1958	1.658	133.795
1959	0.874	146.443
1960	0.638	152.630
1961	0.466	159.201
1962	0.375	163.951
1963	0.307	169.801
1964	0.271	162.450
1965	0.223	154.061
1966	0.212	171.538
1967	0.162	166.824
1968	0.132	172.963
1969	0.132	187.123
1970	0.138	197.215

TABLE A.9

ELECTRICITY PRODUCED BY PRIMARY ENERGY SOURCES (KWH. x 10^9)

YEAR	COAL	NATURAL GAS	CRUDE OIL	NUCLEAR	HYDRO
1945	0.603	0.026	0.069	0.	34.
1946	0.593	0.031	0.074	0.	36.8
1947	0.662	0.043	0.094	0.	40.2
1948	0.729	0.056	0.113	0.	44.2
1949	4.839	0.441	0.839	0.	42.779
1950	5.245	0.590	0.999	0.	46.624
1951	4.733	0.694	1.025	0.	51.955
1952	4.899	0.892	1.207	0.	57.024
1953	6.102	1.401	1.627	0.	58.926
1954	5.897	1.701	1.769	0.	62.572
1955	4.992	1.857	1.617	0.	69.478
1956	1.173	0.569	0.438	0.	81.408
1957	2.074	1.081	0.585	0.	83.373
1958	1.468	1.276	0.431	0.	90.509
1959	1.272	1.783	0.494	0.	97.04
1960	1.403	1.565	0.449	0.	105.883
1961	2.926	3.056	1.048	0.	103.919
1962	7.251	3.394	1.411	0.027	104.051
1963	12.182	3.958	1.432	0.104	103.832
1964	14.532	3.875	2.038	0.169	113.334
1965	18.371	5.572	3.016	0.141	117.063
1966	17.821	5.875	3.236	0.188	129.834
1967	21.538	6.250	5.111	0.164	132.747
1968	25.704	7.233	7.958	0.971	134.973
1969	27.870	4.794	7.048	0.560	149.247
1970	32.975	5.768	5.803	1.080	156.709

TABLE A.10

BTU CONVERSION CONSTANTS[1]

COAL
1×10^6 short tons of coal = .026 Q

NATURAL GAS
1×10^9 cubic feet of natural gas = .00107 Q

CRUDE OIL
1×10^6 barrels of crude oil = .0058 Q

ELECTRICITY
1×10^9 kwh. of electricity = .0094 Q

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[1] 1.0 Q = 1×10^{15} BTU

APPENDIX B

PARAMETER ESTIMATION OF DISTRIBUTION MULTIPLIERS

This appendix presents the methodology and final results of the parameter estimation for the distribution multiplier equations.

The data which was required for the parameter estimation consisted of the proportion of free demand which was satisfied by each fuel in each time period. In order to acquire this data on a sector-by-sector basis, it was necessary to utilize the theoretical structure of the 'Canadian Interfuel Substitution Model' in conjunction with the assumptions made relating to consumer commitment liberation rates. The following equations present the development of an equation for calculating the data for the actual distribution multipliers. This procedure is described for the residential-commercial sector but it applies equally to all the demand sectors.

The methodology begins with the model equation for residential-commercial demand for fuel <u>m</u>.

$$RCD\underline{m}.K = RCD\underline{m}.J + DT*[-RCD\underline{m}DR.JK + RCDD\underline{m}.J* RCMSD.JK] \qquad (B.1)$$

In differential equation form this equation becomes:

$$\frac{d(RCD\underline{m})}{dt} = -RCD\underline{m}DR + (RCDD\underline{m}*RCMSD) \qquad (B.2)$$

and rearranging equation B.2 produces

$$RCDD\underline{m} = \frac{\dfrac{d(RCD\underline{m})}{dt} + RCD\underline{m}DR}{RCMSD} \qquad (B.3)$$

where $RCDD\underline{m}$ = residential-commercial distribution multiplier for fuel $\underline{m}$.
RCMSD = market sensitive (free) demand for the RCD sector.
$RCD\underline{m}DR$ = decline rate of RCD demand for fuel $\underline{m}$.
$\dfrac{d(RCD\underline{m})}{dt}$ = rate of change of RCD demand for fuel $\underline{m}$.

The application of equation B.3 to the actual data will produce the desired data for the actual distribution multiplier. Therefore, the first step in obtaining the actual distribution multipliers was to calculate the free demand in each sector from the collected energy demand data. Although no problems existed with calculating the incremental demand portion of the free demand, it was necessary to use the earlier assumptions regarding the consumer commitment liberation rates in order to calculate the replacement demand portion of the free demand. Once the free demand was calculated, the decline rate of demand for each fuel and the incremental demand for each fuel were easily determined.

Tables B.1 to B.4 contain the actual distribution multipliers as calculated. By definition, these distribution multipliers must sum to 1.0 for any given time period and individually they can never be less than 0.0.

From the data, several parameter estimations were performed[1] for each sector assuming different equation structures. Only the final results are presented here. In the instances where non-linear structures were accepted for the distribution multilpliers it was necessary to make adjustments to the equation to insure that their slope is, at every point, non-positive. These adjustments were accomplished by arbitrarily choosing a slightly smaller price ratio than that which yielded a minimum for the distribution multiplier. From the point on the non-linear curve corresponding to this price ratio a straight line was specified which had an equal first derivative to the initial function at the point of intersection. Wherever these adjustments occured they will be presented with the parameter estimation results. As a result, the equations described below for the distribution multipliers are those which were used in the 'Canadian Interfuel Substitution Model'.

RESIDENTIAL-COMMERCIAL SECTOR

$$RCDDW1 = \underset{(2.98)}{35.1764} - \underset{(.073)}{.3437}*PWRATIO - \underset{(.0015)}{.01776}*TIME, \quad R^2 = .9123 \qquad (B.4)$$

if $PXRATIO \leq .42$,

$$RCDDX1 = \underset{(2.42)}{-17.9388} - \underset{(.289)}{.4514}*PXRATIO + \underset{(.336)}{.5336}*(PXRATIO)^2 + \underset{(.0012)}{.0093}*TIME, \quad R^2 = .7746 \qquad (B.5)$$

---

[1] the technique used was ordinary least squares.

if PXRATIO>.42,

$$RCDDX1 = -18.0343 - .00318*(PXRATIO-.42) + .0093*TIME \quad (B.6)$$

The best estimate for the equation for RCDDY1 was found by trial-and-error and is equal to a constant.

$$RCDDY1 = .44 \quad (B.7)$$

$$\underset{(3.384)}{RCDDZ1 = -19.3065} - \underset{(.0248)}{.0212}*PZRATIO + \underset{(.0018)}{.0101}*TIME,\ R^2 = .6509 \quad (B.8)$$

In every instance where a statistically estimated equation was accepted, all of the estimated parameters were significantly different from zero in a statistical sense (90% level of confidence) except for the coefficient of PZRATIO in the equation for RCDDZ1. Despite this fact, the coefficient of PZRATIO was maintained at its estimated value for use in the model.

INDUSTRIAL SECTOR

Since the coefficient of PWRATIO in the equation for IHDDW1 was not significantly different from zero and it possessed the wrong sign; it was omitted from the equation.

$$IHDDW1 = \underset{(3.863)}{21.1355} - \underset{(.0020)}{.0107}*TIME,\ R^2 = .5651 \quad (B.9)$$

if PXRATIO≤.40,

$$IHDDX1 = \underset{(2.839)}{-26.8776} - \underset{(.348)}{.6519}*PXRATIO + \underset{(.393)}{.7956}*(PXRATIO)^2 + \underset{(.0015)}{.0139}*TIME,\ R^2 = .8395 \quad (B.10)$$

if PXRATIO>.40,

$$IHDIX1 = -27.0111 - .0154*(PXRATIO-.40) + .0139*TIME \qquad (B.11)$$

$$\underset{(3.893)}{IHDDY1 = -9.5911} - \underset{(.061)}{.012}*PYRATIO + \underset{(.002)}{.00504}*TIME, \; R^2 = .1821 \qquad (B.12)$$

$$\underset{(6.282)}{IHDDZ1 = 12.9621} - \underset{(.044)}{.0112}*PZRATIO - \underset{(.0033)}{.0064}*TIME, \; R^2 = .2061 \qquad (B.13)$$

Although the coefficients of PYRATIO and PZRATIO in the equation for IHDDY1 and IHDDZ1 respectively were not significantly different from zero, they were not removed from the equations for use in the model.

TRANSPORTATION SECTOR

$$\underset{(5.537)}{TRDDW1 = 45.8318} - \underset{(.139)}{.2718}*PWRATIO \; \underset{(.0028)}{.0232}*TIME. \; R^2 = .7782 \qquad (B.14)$$

$$\underset{(5.799)}{TRDDY1 = -47.6536} - \underset{(.095)}{.0077}*PYRATIO + \underset{(.003)}{.0248}*TIME, \; R^2 = .7395 \qquad (B.15)$$

The coefficient of PYRATIO was maintained in the model at its estimated value despite the fact that it is not significantly different from zero at a 90% level of confidence.

ELECTRICITY GENERATING SECTOR

if PWRATIO$\leq$.74

$$ZDDW1 = \underset{(13.876)}{-16.1974} - \underset{(3.959)}{4.9351}*PWRATIO + \underset{(3.032)}{3.2931}*(PWRATIO)^2$$

$$+ \underset{(.0073)}{.0095}*TIME, \; R^2 = .0764 \qquad (B.16)$$

if PWRATIO>.74

$$ZDDW1 = -18.04607 - .0613*(PWRATIO-.74)$$

$$+ .0095*TIME \qquad (B.17)$$

if PXRATIO$\leq$.66

$$ZDDX1 = \underset{(8.566)}{14.2029} - \underset{(1.069)}{1.9510}*PXRATIO + \underset{(1.181)}{1.4762}*(PXRATIO)^2$$

$$- \underset{(.0044)}{.0069}*TIME, \; R^2 = .4129 \qquad (B.18)$$

if PXRATIO>.66

$$ZDDX1 = 13.5644 - .002416*(PXRATIO-.66)$$

$$- .0069*TIME \qquad (B.19)$$

if PYRATIO$\leq$< 1.21

$$ZDDY1 = \underset{(.299)}{.5745} - \underset{(.385)}{.7104}*PYRATIO$$

$$+ \underset{(.123)}{.2922}*(PYRATIO)^2, \; R^2 = .4597 \qquad (B.20)$$

if PYRATIO>1.21

$$ZDDY1 = 14.273 - .00328*(PYRATIO-1.21) \qquad (B.21)$$

For the primary demand sectors it is interesting to note that only the distribution multiplier for natural gas responds to the relative fuel price in a non-linear manner. This has been interpreted by Khazzoom to mean that the influence of relative price changes declines as the relative price increases.

TABLE B.1

CALCULATED DISTRIBUTION MULTIPLIERS FOR THE RESIDENTIAL-COMMERCIAL DEMAND SECTOR

YEAR	COAL	NATURAL GAS	CRUDE OIL	ELECTRICITY
1945	0.47	0.06	0.32	0.15
1946	0.41	0.06	0.36	0.17
1947	0.49	0.09	0.15	0.27
1948	0.42	0.1	0.22	0.26
1949	0.34	0.06	0.36	0.24
1950	0.3	0.07	0.39	0.24
1951	0.08	0.05	0.49	0.37
1952	0.26	0.07	0.38	0.29
1953	0.18	0.1	0.45	0.26
1954	0.23	0.11	0.38	0.27
1955	0.15	0.1	0.47	0.28
1956	0.09	0.19	0.37	0.35
1957	0.13	0.2	0.4	0.28
1958	0.08	0.23	0.38	0.32
1959	0.07	0.22	0.39	0.32
1960	0.09	0.18	0.36	0.37
1961	0.05	0.2	0.4	0.35
1962	0.04	0.15	0.49	0.32
1963	0.03	0.19	0.45	0.33
1964	0.01	0.21	0.48	0.3
1965	0.01	0.2	0.32	0.47
1966	0.01	0.21	0.37	0.41
1967	0.0	0.2	0.34	0.46
1968	0.01	0.25	0.33	0.41
1969	----	----	----	----
1970	----	----	----	----

TABLE B.2

CALCULATED DISTRIBUTION MULTIPLIERS FOR THE INDUSTRIAL DEMAND SECTOR

YEAR	COAL	NATURAL GAS	CRUDE OIL	ELECTRICITY
1945	0.31	0.04	0.11	0.54
1946	----	----	----	----
1947	0.24	0.04	0.24	0.48
1948	0.31	0.03	0.12	0.53
1949	0.32	0.04	0.09	0.54
1950	0.23	0.04	0.18	0.55
1951	0.21	0.03	0.12	0.64
1952	0.36	0.03	0.09	0.52
1953	0.08	0.08	0.29	0.55
1954	0.31	0.11	0.19	0.39
1955	0.25	0.11	0.25	0.39
1956	0.24	0.12	0.16	0.47
1957	0.16	0.13	0.15	0.56
1958	0.13	0.27	0.2	0.4
1959	0.15	0.17	0.17	0.52
1960	0.17	0.27	0.29	0.26
1961	0.17	0.2	0.24	0.39
1962	0.18	0.2	0.28	0.34
1963	0.18	0.18	0.15	0.49
1964	0.17	0.2	0.19	0.44
1965	0.08	0.25	0.23	0.43
1966	0.12	0.24	0.26	0.38
1967	0.05	0.26	0.34	0.35
1968	0.02	0.29	0.17	0.53
1969	----	----	----	----
1970	----	----	----	----

TABLE B.3

CALCULATED DISTRIBUTION MULTIPLIERS FOR THE TRANSPORTATION DEMAND SECTOR

YEAR	COAL	CRUDE OIL
1945	0.52	0.48
1946	0.59	0.41
1947	0.38	0.62
1948	0.46	0.54
1949	0.2	0.8
1950	0.41	0.59
1951	0.5	0.5
1952	0.46	0.54
1953	0.35	0.65
1954	0.33	0.67
1955	0.22	0.78
1956	0.04	0.96
1957	0.04	0.96
1958	0.01	0.99
1959	0.03	0.97
1960	0.02	0.98
1961	0.03	0.97
1962	0.02	0.98
1963	0.05	0.95
1964	0.04	0.96
1965	0.01	0.99
1966	0.	1.0
1967	0.	1.0
1968	0.	1.0
1969	0.01	0.99
1970	----	----

TABLE B.4

CALCULATED DISTRIBUTION MULTIPLIERS FOR THE ELECTRICITY GENERATING SECTOR

YEAR	COAL	NATURAL GAS	CRUDE OIL
1945	0.73	0.1	0.17
1946	0.75	0.09	0.16
1947	0.74	0.1	0.16
1948	0.79	0.07	0.14
1949	0.67	0.15	0.18
1950	0.04	0.54	0.42
1951	0.54	0.22	0.24
1952	0.6	0.21	0.19
1953	0.35	0.38	0.26
1954	----	----	----
1955	0.61	0.2	0.19
1956	0.57	0.32	0.11
1957	----	----	----
1958	----	----	----
1959	----	----	----
1960	0.42	0.42	0.16
1961	0.18	0.11	0.08
1962	0.84	0.13	0.02
1963	0.77	0.07	0.16
1964	0.62	0.24	0.14
1965	0.48	0.32	0.2
1966	0.63	0.11	0.25
1967	0.56	0.14	0.3
1968	----	----	----
1969	----	----	----
1970	----	----	----

APPENDIX C

MODEL LISTING

This appendix contains a listing of the "Canadian Interfuel Substitution Model". The computer language employed is known as DYNAMO (21).

The exogenous variables in the model as it is listed here are those that were assumed for CASE III of the projections.

```
* CANADIAN INTERFUEL SUBSTITUTION MODEL
NOTE      TOTAL PRIMARY ENERGY CONSUMPTION
A TPEC.K=WD.K+XD.K+YD.K+NTOZ.K+HTOZ.K
NOTE      TOTAL ENERGY DEMAND BY PRIMARY CONSUMING SECTORS
A TED.K=WO.K+XO.K+YO.K+ZO.K
NOTE
NOTE
NOTE       RESIDENTIAL AND COMMERCIAL DEMAND SECTOR
NOTE
L RCD.K=RCD.J+DT*(RCDGR.JK)
N RCD=.38
A RCDG.K=RCDRG*RCD.K
C RCDRG=.071
R RCDGR.KL=RCDG.K
NOTE      REPLACEMENT DEMANDS
A RCWRD.K=RCDW.K*RCWB
A RCXRD.K=RCDX.K*RCXB.K
A RCYRD.K=RCDY.K*RCYB.K
A RCZRD.K=RCDZ.K*RCZB
NOTE      MARKET SENSITIVE DEMAND
A RCMSD1.K=RCDG.K+RCWRD.K+RCXRD.K+RCYRD.K+RCZRD.K
R RCMSD.KL=RCMSD1.K
NOTE      DECAY RATES
R RCDWDR.KL=RCWRD.K
R RCDXDR.KL=RCXRD.K
R RCDYDR.KL=RCYRD.K
R RCDZDR.KL=RCZRD.K
NOTE      LEVELS OF FUEL CONSUMPTION
L RCDW.K=RCDW.J+DT*(-RCDWDR.JK+RCDDW.J*RCMSD.JK)
N RCDW=.27
L RCDX.K=RCDX.J+DT*(-RCDXDR.JK+RCDDX.J*RCMSD.JK)
N RCDX=.02
L RCDY.K=RCDY.J+DT*(-RCDYDR.JK+RCDDY.J*RCMSD.JK)
N RCDY=.03
L RCDZ.K=RCDZ.J+DT*(-RCDZDR.JK+RCDDZ.J*RCMSD.JK)
```

```
N RCDZ=.06
NOTE      DISTRIBUTION MULTIPLIERS
C RW=.3437
C RWT=.01776
A RCDDWO.K=35.1764-(RW*PWRATIO.K)-(RWT*TIME.K)
A RCDDW1.K=MAX(RCDDWO.K,0.0)
A RCDDXO.K=(-17.9388)-(.4514*PXRATIO.K)+(.5336*PXRATIO.K*PXRATIO.K)+(.00
X 93*TIME.K)
A RCDDXA.K=(-18.0488)-(.00318*(PXRATIO.K-.42))+(.0093*TIME.K)
A RCDDXC.K=CLIP(RCDDXA.K,RCDDXC.K,PXRATIO.K,.42)
A RCDDX1.K=MAX(RCDDXC.K,0.0)
C RY1=.44
A RCDDY1.K=RY1
A RCDDZO.K=(-19.3065)-(.0212*PZRATIO.K)+(.0101*TIME.K)
A RCDDZ1.K=MAX(RCDDZO.K,0.0)
A RTOTAL.K=RCDDW1.K+RCDDX1.K+RCDDY1.K+RCDDZ1.K
A RCDDW.K=RCDDW1.K/RTOTAL.K
A RCDDX.K=RCDDX1.K/RTOTAL.K
A RCDDY.K=RCDDY1.K/RTOTAL.K
A RCDDZ.K=RCDDZ1.K/RTOTAL.K
NOTE        CONSUMER COMMITMENT LIBERATION RATES
C RCWB=.20
A RCXB.K=CLIP(RXXB.K,RXXX.K,1975.0,TIME.K)
A RXXB.K=.10
A RXXX.K=TABHL(RXTAB,TIME.K,1975.0,1985.0,5.0)
T RXTAB=.1/.15/.2
A RCYB.K=CLIP(RYYB.K,RYYY.K,1975.0,TIME.K)
A RYYB.K=.1
A RYYY.K=TABHL(RYTAB,TIME.K,1975.0,1985.0,5.0)
T RYTAB=.1/.2/.3
C RCZB=0.10
NOTE
NOTE
NOTE
NOTE
```

```
NOTE        INDUSTRIAL DEMAND SECTOR
NOTE
NOTE
NOTE
L IHD.K=IHD.J+DT*(IHDGR.JK)
N IHD=.667
A IHDG.K=IHDRG*IHD.K
C IHDRG=.045
R IHDGR.KL=IHDG.K
NOTE      REPLACEMENT DEMANDS
A IHWRD.K=IHDW.K*IHWB.K
A IHXRD.K=IHDX.K*IHXB.K
A IHYRD.K=IHDY.K*IHYB.K
A IHZRD.K=IHDZ.K*IHZB
NOTE      MARKET SENSITIVE DEMAND
A IHMSD1.K=IHDG.K+IHWRD.K+IHXRD.K+IHYRD.K+IHZRD.K
R IHMSD.KL=IHMSD1.K
NOTE      DECAY RATES
R IHDWDR.KL=IHWRD.K
R IHDXDR.KL=IHXRD.K
R IHDYDR.KL=IHYRD.K
R IHDZDR.KL=IHZRD.K
NOTE      LEVELS OF FUEL CONSUMPTION
L IHDW.K=IHDW.J+DT*(-IHDWDR.JK+IHDDW.J*IHMSD.JK)
N IHDW=.31
L IHDX.K=IHDX.J+DT*(-IHDXDR.JK+IHDDX.J*IHMSD.JK)
N IHDX=.00
L IHDY.K=IHDY.J+DT*(-IHDYDR.JK+IHDDY.J*IHMSD.JK)
N IHDY=.111
L IHDZ.K=IHDZ.J+DT*(-IHDZDR.JK+IHDDZ.J*IHMSD.JK)
N IHDZ=.25
NOTE      DISTRIBUTION MULTIPLIERS
C IWT=.01067
A IHDDWO.K=21.1355-(IWT*TIME.K)
A IHDDW1.K=MAX(IHDDWO.K,0.0)
```

```
C IXT=.0139
A IHDDXA.K=(-27.0111)-(.0154*(PXRATIO.K-.40))+(.0139*TIME.K)
A IHDDXO.K=(-26.8776)-(.6519*PXRATIO.K)+(.7956*PXRATIO.K*PXRATIO.K)+(IXT
X *TIME.K)
A IHDDXC.K=CLIP(IHDDXA.K,IHDDXO.K,PXRATIO.K,.40)
A IHDDX1.K=MAX(IHDDXC.K,0.0)
C IYT=.00504
A IHDDYO.K=(-9.5911)-(.0120*PYRATIO.K)+(IYT*TIME.K)
A IHDDY1.K=MAX(IHDDYO.K,0.0)
C IZT=.0063
A IHDDZO.K=12.9621-(.0112*PZRATIO.K)-(IZT*TIME.K)
A IHDDZ1.K=MAX(IHDDZO.K,0.0)
A ITOTAL.K=IHDDW1.K+IHDDX1.K+IHDDY1.K+IHDDZ1.K
A IHDDW.K=IHDDW1.K/ITOTAL.K
A IHDDX.K=IHDDX1.K/ITOTAL.K
A IHDDY.K=IHDDY1.K/ITOTAL.K
A IHDDZ.K=IHDDZ1.K/ITOTAL.K
NOTE       CONSUMER COMMITMENT LIBERATION RATES
A IHWB.K=CLIP(IWWB.K,IWWW.K,1970.0,TIME.K)
A IWWW.K=.35
A IWWB.K=TABHL(IWWTAB,TIME.K,1945.0,1970.0,1.0)
T IWWTAB=.1/.1/.1/.1/.1/.1/.1/.1/.15/.15/.15/.2/.2/.2/.2/.2/.2/.2/.2/.2/
X .2/.2/.2/.2/.35/.35
A IHXB.K=RCXB.K
A IHYB.K=RCYB.K
C IHZB=0.10
NOTE
NOTE
NOTE
NOTE
NOTE       TRANSPORTATION DEMAND SECTOR
NOTE
NOTE
NOTE
L TRD.K=TRD.J+DT*(TRDGR.JK)
```

```
N TRD=.536
A TRDG.K=TRDRG*TRD.K
C TRDRG=.0306
R TRDGR.KL=TRDG.K
NOTE     REPLACEMENT DEMANDS
A TRWRD.K=TRDW.K*TRWB.K
A TRXRD.K=TRDX.K*TRXB
A TRYRD.K=TRDY.K*TRYB
A TRZRD.K=TRDZ.K*TRZB
NOTE     MARKET SENSITIVE DEMAND
A TRMSD1.K=TRDG.K+TRWRD.K+TRXRD.K+TRYRD.K+TRZRD.K
R TRMSD.KL=TRMSD1.K
NOTE     DECAY RATES
R TRDWDR.KL=TRWRD.K
R TRDXDR.KL=TRXRD.K
R TRDYDR.KL=TRYRD.K
R TRDZDR.KL=TRZRD.K
NOTE     LEVELS OF FUEL CONSUMPTION
L TRDW.K=TRDW.J+DT*(-TRDWDR.JK+TRDDW.J*TRMSD.JK)
N TRDW=TRDWI
C TRDWI=.315
L TRDX.K=TRDX.J+DT*(-TRDXDR.JK+TRDDX.J*TRMSD.JK)
N TRDX=0.0
L TRDY.K=TRDY.J+DT*(-TRDYDR.JK+TRDDY.J*TRMSD.JK)
N TRDY=.20
L TRDZ.K=TRDZ.J+DT*(-TRDZDR.JK+TRDDZ.J*TRMSD.JK)
N TRDZ=.00
NOTE     DISTRIBUTION MULTIPLIERS
A TRDDWO.K=45.8318-(.2718*PWRATIO.K)-(.0232*TIME.K)
A TRDDW1.K=MAX(TRDDWO.K,0.0)
A TRDDX1.K=0.0
A TRDDYO.K=(-47.6536)-(.0077*PYRATIO.K)+(.0248*TIME.K)
A TRDDY1.K=MAX(TRDDYO.K,0.0)
A TRDDZ1.K=0.0
A TTOTAL.K=TRDDW1.K+TRDDX1.K+TRDDY1.K+TRDDZ1.K
```

```
A TRDDW.K=TRDDW1.K/TTOTAL.K
A TRDDX.K=TRDDX1.K/TTOTAL.K
A TRDDY.K=TRDDY1.K/TTOTAL.K
A TRDDZ.K=TRDDZ1.K/TTOTAL.K
NOTE        CONSUMER COMMITMENT LIBERATION RATES
A TRWB.K=CLIP(TWWB.K,TWWW.K,1970.0,TIME.K)
A TWWB.K=TABHL(TWWTAB,TIME.K,1945.0,1970.0,1.0)
T TWWTAB=.1/.1/.1/.1/.2/.3/.4/.45/.45/.45/.45/.45/.5/.5/.45/.45/.45/.45/
X .45/.45/.4/.3/.25/.25/.25/.25
A TWWW.K=.25
C TRXB=.20
C TRYB=.10
C TRZB=.20
NOTE
NOTE
NOTE     ENERGY CONSUMPTION BY PRIMARY CONSUMING SECTORS
NOTE
A WO.K=RCDW.K+IHDW.K+TRDW.K
A XO.K=RCDX.K+IHDX.K+TRDX.K
A YO.K=RCDY.K+IHDY.K+TRDY.K
A ZO.K=RCDZ.K+IHDZ.K+TRDZ.K
NOTE
NOTE        ELECTRICITY GENERATING SECTOR
NOTE     INCREMENTAL DEMAND
A ZDG2.K=(RCDDZ.K*RCMSD1.K)-RCZRD.K+(TRDDZ.K*TRMSD1.K)-TRZRD.K
A ZDG1.K=ZDG2.K+(IHDDZ.K*IHMSD1.K)-IHZRD.K
NOTE     REPLACEMENT DEMANDS
A ZFWRD.K=ZFW.K*ZFWB.K
A ZFXRD.K=ZFX.K*ZFXB.K
A ZFYRD.K=ZFY.K*ZFYB.K
NOTE     MARKET SENSITIVE DEMAND
NOTE     NUCLEAR MARKET SHARE
A ZFN.K=(1.0-FCF.K)(ZO.K)
A FCF.K=TABLE(FCFTAB,TIME.K,1945.0,1985.0,5.0)
T FCFTAB=1.0/1.0/1.0/1.0/1.0/.995/.945/.89/.826
```

```
A ZFH.K=TABLE(ZFHTAB,TIME.K,1945.0,1985.0,1.0)
T ZFHTAB=.32/.346/.378/.415/.402/.438/.498/.536/.554/.588/.653/.765/.784
X /.851/.912/.995/.977/.978/.976/1.065/1.1/1.22/1.248/1.269/1.403/1.473/
X 1.505/1.556/1.65/1.704/1.8/1.855/1.953/2.05/2.12/2.2/2.28/2.35/2.43/2.
X 5/2.57
A HRF.K=0.011+.004*EXP(-.4*(TIME.K-1945.0))
C HRN=0.0104
NOTE     FOSSIL MARKET SENSITIVE DEMAND
R ZNEW.KL=ZFN.K
A ZFND.K=ZNEW.JK
N ZNEW=0.0
R ZNOW.KL=ZFH.K
A ZFHD.K=ZNOW.JK
N ZNOW=.29
A DELZFN.K=ZFN.K-ZFND.K
A DELZFH.K=ZFH.K-ZFHD.K
A ZFFG.K=ZDG1.K-(DELZFN.K/DT)-(DELZFH.K/DT)
R ZFSD.KL=ZFFG.K+ZFWRD.K+ZFXRD.K+ZFYRD.K
NOTE     FUEL DECAY RATES
R ZFWDR.KL=ZFWRD.K
R ZFXDR.KL=ZFXRD.K
R ZFYDR.KL=ZFYRD.K
NOTE     ELECTRICITY OUTPUT PRODUCED FROM W,X, AND Y
L ZFW.K=ZFW.J+DT*(-ZFWDR.JK+ZDDW.J*ZFSD.JK)
N ZFW=.008
L ZFX.K=ZFX.J+DT*(-ZFXDR.JK+ZDDX.J*ZFSD.JK)
N ZFX=0.0
L ZFY.K=ZFY.J+DT*(-ZFYDR.JK+ZDDY.J*ZFSD.JK)
N ZFY=.001
NOTE
A WTOZ.K=ZFW.K*HRF.K/(.0094)
A XTOZ.K=ZFX.K*HRF.K/(.0094)
A YTOZ.K=ZFY.K*HRF.K/(.0094)
A NTOZ.K=ZFN.K*HRN/(.0094)
A HTOZ.K=ZFH.K*HRF.K/(.0094)
```

```
NOTE     DISTRIBUTION FACTORS
A ZDDWO.K=(-16.1974)-(4.9351*PWRATIO.K)+(3.2931*PWRATIO.K*PWRATIO.K)+(.0
X 095*TIME.K)
A ZDDWA.K=(-18.04607)-(.0613*(PWRATIO.K-.74))+(.0095*TIME.K)
A ZLDWC.K=CLIP(ZDDWA.K,ZDDWO.K,PWRATIO.K,.74)
A ZDDW1.K=MAX(ZDDWC.K,0.0)
A ZDDXO.K=14.2090-(1.9510*PXRATIO.K)+(1.4762*PXRATIO.K*PXRATIO.K)-(.0069
X *TIME.K)
A ZDDXA.K=(13.5644)-(.002416*(PXRATIO.K-.66))-(.0069*TIME.K)
A ZDDXC.K=CLIP(ZDDXA.K,ZDDXO.K,PXRATIO.K,.66)
A ZDDX1.K=MAX(ZDDXC.K,0.0)
A ZDDYO.K=.5745-(.7104*PYRATIO.K)+(.2922*PYRATIO.K*PYRATIO.K)
A ZDDYA.K=(.14273)-(.00328*(PYRATIO.K-1.21))
A ZDDYC.K=CLIP(ZDDYA.K,ZDDYO.K,PYRATIO.K,1.21)
A ZDDY1.K=MAX(ZDDYC.K,0.0)
A ZTOTAL.K=ZDDW1.K+ZDDX1.K+ZDDY1.K
A ZDDW.K=(ZDDW1.K/ZTOTAL.K)
A ZDDX.K=(ZDDX1.K/ZTOTAL.K)
A ZDDY.K=(ZDDY1.K/ZTOTAL.K)
NOTE       CONSUMER COMMITMENT LIBERATION RATES
A ZFWB.K=RCXB.K
A ZFXB.K=RCXB.K
A ZFYB.K=RCXB.K
NOTE
NOTE
NOTE     FUEL CONSUMPTION
A WD.K=WO.K+WTOZ.K
A XD.K=XO.K+XTOZ.K
A YD.K=YO.K+YTOZ.K
A ZD.K=ZO.K
NOTE       FUEL PRICES
A PW.K=CLIP(PA.K,PB.K,1970.0,TIME.K)
A PA.K=TABHL(APTAB,TIME.K,1945.0,1970.0,5.0)
T APTAB=.14/.14/.14/.14/.12/.09
A PB.K=TABHL(BPTAB,TIME.K,1970.0,1985.0,1.0)
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```
T BPTAB=.09/.11/.12/.12/.13/.14/.15/.16/.18/.18/.2/.21/.23/.24/.26/.27
A PX.K=CLIP(PC.K,PD.K,1970.0,TIME.K)
A PC.K=TABHL(CPTAB,TIME.K,1945.0,1970.0,5.0)
T CPTAB=.14/.09/.07/.06/.05/.05
A PD.K=TABHL(DPTAB,TIME.K,1970.0,1985.0,1.0)
T DPTAB=.05/.057/.053/.056/.065/.075/.083/.09/.1/.11/.12/.13/.14/.148/.1
X 58/.168
A PY.K=CLIP(PE.K,PF.K,1970.0,TIME.K)
A PE.K=TABHL(EPTAB,TIME.K,1945.0,1970.0,5.0)
T EPTAB=.32/.26/.23/.22/.21/.20
A PF.K=TABHL(FPTAB,TIME.K,1970.0,1985.0,1.0)
T FPTAB=.2/.21/.21/.23/.25/.275/.3/.325/.35/.38/.41/.44/.48/.51/.55/.6
A PZ.K=CLIP(PG.K,PH.K,1970.0,TIME.K)
A PG.K=TABHL(GPTAB,TIME.K,1945.0,1970.0,5.0)
T GPTAB=.57/.48/.44/.43/.42/.42
A PH.K=TABHL(HPTAB,TIME.K,1970.0,1985.0,1.0)
T HPTAB=.42/.42/.41/.42/.42/.43/.43/.44/.45/.46/.47/.48/.51/.53/.56/.6
NOTE
NOTE        FUEL PRICE RATIOS
A PXRATIO.K=PX.K/(EXP((LOGN(PY.K*PW.K*PZ.K))/3.0))
A PYRATIO.K=PY.K/(EXP((LOGN(PX.K*PW.K*PZ.K))/3.0))
A PWRATIO.K=PW.K/(EXP((LOGN(PX.K*PY.K*PZ.K))/3.0))
A PZRATIO.K=PZ.K/(EXP((LOGN(PX.K*PY.K*PW.K))/3.0))
NOTE
NOTE        FUEL MARKET SHARES IN ELECTRICITY GENERATION SECTOR
S EWMS.K=ZFW.K/ZD.K
S EXMS.K=ZFX.K/ZD.K
S EYMS.K=ZFY.K/ZD.K
S ENMS.K=ZFN.K/ZD.K
S EHMS.K=ZFH.K/ZD.K
NOTE        TOTAL MARKET SHARES
S WMS.K=WD.K/TPEC.K
S XMS.K=XD.K/TPEC.K
S YMS.K=YD.K/TPEC.K
S NMS.K=NTOZ.K/TPEC.K
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S HMS.K=HTOZ.K/TPEC.K
NOTE
NOTE
C PLTPER=1.0
PRINT TPEC,RCD,IHD,TRD,ZD,WD,XD,YD,WO,XO,YO,PZ,PW,PX,PY
PRINT IHDW,IHDX,IHDY,IHDZ,TRDW,TRDX,TRDY,TRDZ
PRINT XTOZ,XTOZ,YTOZ,NTOZ,HTOZ
PRINT ZFN,ZFH,ZFW,ZFX,ZFY
PRINT RCDW,RCDX,RCDY,RCDZ
PRINT ZFFG,ZDG1,DELZFH,ZFSD
PRINT EWMS,EXMS,EYMS,ENMS,EHMS
PRINT WMS,XMS,YMS,NMS,HMS
PLOT PW=W,PX=X,PY=Y,PZ=Z
PLOT PXRATIO=X,PWRATIO=W,PYRATIO=Y,PZRATIO=Z
PLOT RCD=R,IHD=I,TRD=T,ZD=E,TED=D
PLOT RCDW=W,RCDX=X,RCDY=Y,RCDZ=Z
PLOT RCDDW=W,RCDDX=X,RCDDY=Y,RCDDZ=Z
PLOT IHDW=W,IHDX=X,IHDY=Y,IHDZ=Z
PLOT IHDDW=W,IHDDX=X,IHDDY=Y,IHDDZ=Z
PLOT TRDW=W,TRDX=X,TRDY=Y,TRDZ=Z
PLOT TRDDW=W,TRDDY=Y
PLOT ZFH=H,ZFN=N
PLOT ZFW=W,ZFX=X,ZFY=Y
PLOT ZDDW=W,ZDDX=X,ZDDY=Y
PLOT EWMS=W,EXMS=X,EYMS=Y,ENMS=N,EHMS=H
PLOT WTOZ=W,XTOZ=X,YTOZ=Y
PLOT WO=W,XO=X,YO=Y,ZO=Z
PLOT WD=W,YD=Y,XD=X,ZD=Z
PLOT WMS=W,XMS=X,YMS=Y,NMS=N,HMS=H
C DT=.10
C LENGTH=1985.0
N TIME=1945.0
C PRTPER=1.0
RUN 1
```